# SOIL SCIENCE

## VOLUME 64

### JULY TO DECEMBER, 1947

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# LATERITE DEVELOPED ON ACID ROCKS IN SOUTHWESTERN AUSTRALIA

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Much of the southern part of Western Australia consists of a peneplain about 1,000 to 1,200 feet above sea level and underlain principally by complex rocks of the Pre-Cambrian shield (fig. 1). Extensive areas of this peneplain are capped by laterite, which was early recognized as such by Simpson (17) and Woolnough (19). It was at one time examined in some detail by Campbell (1).

Laterite may be defined as a residual product of rock weathering, often rich in free alumina. The laterization process consists of thorough leaching and deposition in the region of the water-table variation (1), whereby silica and bases removed from the weathered rock leave residual or deposited alumina. Laterization of basic rocks (5) results in the formation of gibbsitic laterite and bauxite, whereas acid rocks yield kaolinite with a considerable amount of free silica as quartz (4, 7).

Common usage of the term "laterite" in Western Australia has restricted its meaning to the hard rock laterite capping a lateritic profile. The profiles described here, and those generally occurring, consist of the following horizons from the surface downward:

Sand or sandy soil often with lateritic gravel (decemented fragments or pisolites of massive laterite).
Massive laterite, generally pisolitic.
Lithomarge, often mottled red and white, cream, or gray.
Kaolinized rock, with or without original rock structure.

Dissection of the peneplain has resulted in the partial removal of the massive laterite and exposure of the underlying lithomarge and kaolinized rock, which are readily seen in the cliffs of "breakaways" (a term used for the edge of the old peneplain) in the interior but which are not always so obvious elsewhere.

From the point of view of soil science, laterite is considered to be a fossil illuvial horizon of an ancient soil, a fact first recognized by Prescott (13). Such ancient soils were formed under hot humid conditions over wide areas in Australia in late Miocene or Pliocene times. In Western Australia the main development may be considered post-Miocene, as laterite occurs on the Plantagenet beds of Miocene sediments near the south coast. It is probable, however, that the period of laterization varies appreciably in different parts of the state.

It has long been recognized that both "high-level" (at about 700 feet) and "low-level" (at about 250 feet) laterites occur. A recent paper by Prider (15) helps to elucidate the problem of the origin of these two varieties.

Disintegration of the laterite capping has resulted in utilization of all parts of a laterite profile as parent materials in the present cycle of soil formation. This results in very complex soil patterns in the southwestern corner of Australia, as noted by Prescott (14).

Because of their widespread occurrence and low fertility, soils representing old laterite horizons or incorporating lateritic material are of considerable economic importance as a limiting factor in land utilization. The approximate extent of the area in which complete or truncated high-level laterite profiles occur is shown by the peneplain in figure 1.

Three profiles representative of high-level laterite developed on gneissic and granitic rocks are described in this paper. The profiles occur near the western edge of the peneplain about 1,000 feet above sea level. Samples from the various horizons were obtained, but in no case was it possible to find the unaltered parent rock in the immediate vicinity, although outcrops occurred at much lower levels some distance from the sections sampled.

This investigation was undertaken to provide some definite chemical and mineralogical information to serve as a background for soil studies in Western Australia.

## METHODS OF EXAMINATION

### Preparation of samples

Each of the profiles has on the surface a sandy layer which contains pebbles of lateritic material. This sandy soil was sieved into two fractions, one containing the pebbles (pisolites), and the other the sand. The latter was sieved with Tyler standard sieves (see table 3). A representative sample of the pisolites, or fragments of massive laterite, and of the material from the other horizons of the profiles was carefully crushed to pass a sieve with mesh openings of 0.14 mm. and used for chemical and mineralogical examinations.

### Mineralogical examination

The crushed samples were reduced by quartering to convenient size for separation in bromoform (sp. gr. 2.8) to obtain the heavy residues, which after being weighed were further separated into magnetic and nonmagnetic fractions (see table 2). The light fraction and the heavy nonmagnetic residues were examined microscopically. The refractive index of the clay minerals was obtained by immersion in liquids, as were the indexes of minerals from different parts of the laterite structure.

### Chemical analysis

The chemical methods used in the analysis of the various parts of the profiles were those generally employed for the analysis of oxide-bearing and argillaceous materials. These, in brief, consisted of treating the crushed material with concentrated HCl to dissolve basic oxides, fuming strongly in $H_2SO_4$ to decompose clays and to dissolve more resistant oxides, and determining silica in the insoluble residue.

The residue from the $SiO_2$ determination was fused with a 1:1 $Na_2CO_3$ – $K_2CO_3$ mixture and added to the filtrate, from which the ammonia precipitate was recovered by a double precipitation. Silica in the precipitate was determined. Free $SiO_2$ was estimated by treating the residue from strong fuming $H_2SO_4$, after filtering and washing twice with 1 per cent NaOH on the filter, and determining the free $SiO_2$ as quartz. This residue contained small amounts of opaline silica. Auxiliary tests showed that about one fifth of the quartz present was dissolved by this treatment, the proportion actually varying with the fineness of grinding of the original sample. Any opaline silica present would be even more subject to attack. The difference between the free $SiO_2$ and the total $SiO_2$ is taken as combined $SiO_2$ and, because of the solubility of quartz, would be somewhat high. In samples containing minerals resistant to fuming $H_2SO_4$, this material would remain in the acid-insoluble residue, decompose with HF, and cause a higher free-$SiO_2$ figure. Such materials showed a large residue from the $SiO_2$ determination and a large amount of $SiO_2$ in the ammonia precipitate and corresponded to samples containing incompletely altered micas.

Free $Al_2O_3$ was estimated by subtracting from the total $Al_2O_3$ the $Al_2O_3$ combined with the $SiO_2$ as kaolinite. In order to assess the free $Al_2O_3$ directly, samples were treated with 50 ml. 5 per cent NaOH solution for 20 minutes at 90° C., the $Al_2O_3$ dissolved being estimated after removal of the $SiO_2$ by fuming with $H_2SO_4$ and filtering. Compared with the conditions used in the commercial Bayer process for extraction of $Al_2O_3$, this treatment is mild, but it is sufficient to dissolve gibbsite, 0.21 gm. kaolinite, and 0.68 gm. halloysite per 100 ml. solution, amounts which are apparently influenced appreciably only by temperature and alkali concentration. Montmorillonite is virtually unattacked.

Total water was estimated directly by the absorption train, and hygroscopic moisture was determined by the loss at 105° C. for 1 hour.

The results of the analyses are given in table 1.

*Use of chemical and optical data in determining minerals present*

In no samples were the principal constituents of the laterites, except quartz, identifiable by the usual optical methods, since these constituents are present in unoriented masses, which even under an oil immersion objective show no crystalline structure. Except for quartz and small quantities of incompletely weathered minerals residual from the parent rock, virtually all the material appeared isotropic, transparent to translucent, and contained minute inclusions. By combining the chemical data and the refractive indexes of the various materials, it has been possible to determine the minerals present and their approximate amounts. Four sets of data were used for the mineral determinations:

*Refractive index.* Throughout the samples the mineral matter was found to be in three refractive index groups, 1.43 (mainly opaline silica), 1.56–1.57, and 1.58–1.64. The groups were fairly well separated, the break between being at least 0.005 of a refractive index unit.

*Alizarin-S adsorption tests.* Hardy and Rodrigues' method (6) was used to establish the presence of free $Al_2O_3$, and the materials were examined under the

microscope. Even in the presence of fair quantities of iron, the tint of the dye could be distinguished. In examining clays for their effect on alizarin-S it was found that unignited halloysite was deeply stained, whereas kaolinite and montmorillonite were stained only a light pink [cf. (6, p. 368)]. The ignited minerals were unaffected. Virtually all grains with a refractive index of 1.58 or greater were uniformly stained, indicating uniform distribution of $Al_2O_3$ throughout the mixture.

*Solubility in hot 5 per cent NaOH solution.* As has been mentioned, gibbsite is completely soluble in hot 5 per cent NaOH solution in 20 minutes. The difference between the alkali-soluble $Al_2O_3$ and the calculated free $Al_2O_3$ shows that some $Al_2O_3$ is present in a form less easily attacked by NaOH solution, presumably boehmite or diaspore. For no better reason than that diaspore seems to be more common than boehmite, this aluminum oxide is here called "diaspore," no definite evidence being available to determine which mineral is present. The maximum refractive index observed is about 1.64, very much less than that of diaspore, showing that if diaspore is present it is intimately mixed with gibbsite or kaolinite. This is borne out by the uniform staining of the grains by alizarin. It is probable that gibbsite forms intimate mixtures with diaspore.

*Ratio of combined water available for hydration of oxides to free $Al_2O_3$.* After calculation (see table 1) of the water equivalent to the combined $SiO_2$ and $Al_2O_3$ as kaolinite, the remainder is available for distribution among the oxides as water of hydration. If all this water is assumed to be present in aluminum hydrates, the molecular ratio of the water to the free $Al_2O_3$ would indicate, within limitations, the possibility of the presence of gibbsite or diaspore. Where the iron occurs largely as magnetite or ilmenite, this assumption is justified; but where there is little of these minerals, the possibility that some water is present in goethite or turgite cannot be overlooked. In calculating the mineralogical composition, the water combined with $Fe_2O_3$ was unknown but was probably small and was therefore neglected. The results of the combined chemical and mineralogical analyses are given in table 2.

### DESCRIPTION OF LATERITE PROFILES

The profiles examined are situated at Wongan Hills (latitude 30°50' S.; longitude 116°40' E.), Greenbushes (33°50'; 116°0'), and Rocky Gully (34°30'; 116°55'), which are shown in figure 1.

### *Wongan Hills*

The profile is exposed in a gravel pit adjacent to the main Wongan Hills-Ballidu road, 2 miles north of Wongan Hills. The soils of this area have been mapped on the Wongan Hills Agricultural Research Station, and it is recognized that they are either the remains of the original laterite capping or are formed from the dissection and erosion of this laterite. The Yaling soil series consists of very gravelly and shallow sandy soils associated with massive laterite or with laterite boulders. The profile described is in the Yaling series, and the country rocks are gneisses and granites.

*Surface.* Sand and lateritic gravel. The gravel consists of decemented massive laterite or groups of pisolites coated with a yellowish brown mixture of diaspore, smaller amounts of gibbsite, and a very little kaolinite and opaline silica. The pisolites are a mixture of iron oxides, gibbsite, some diaspore, and kaolinite in varying proportions, ranging in color
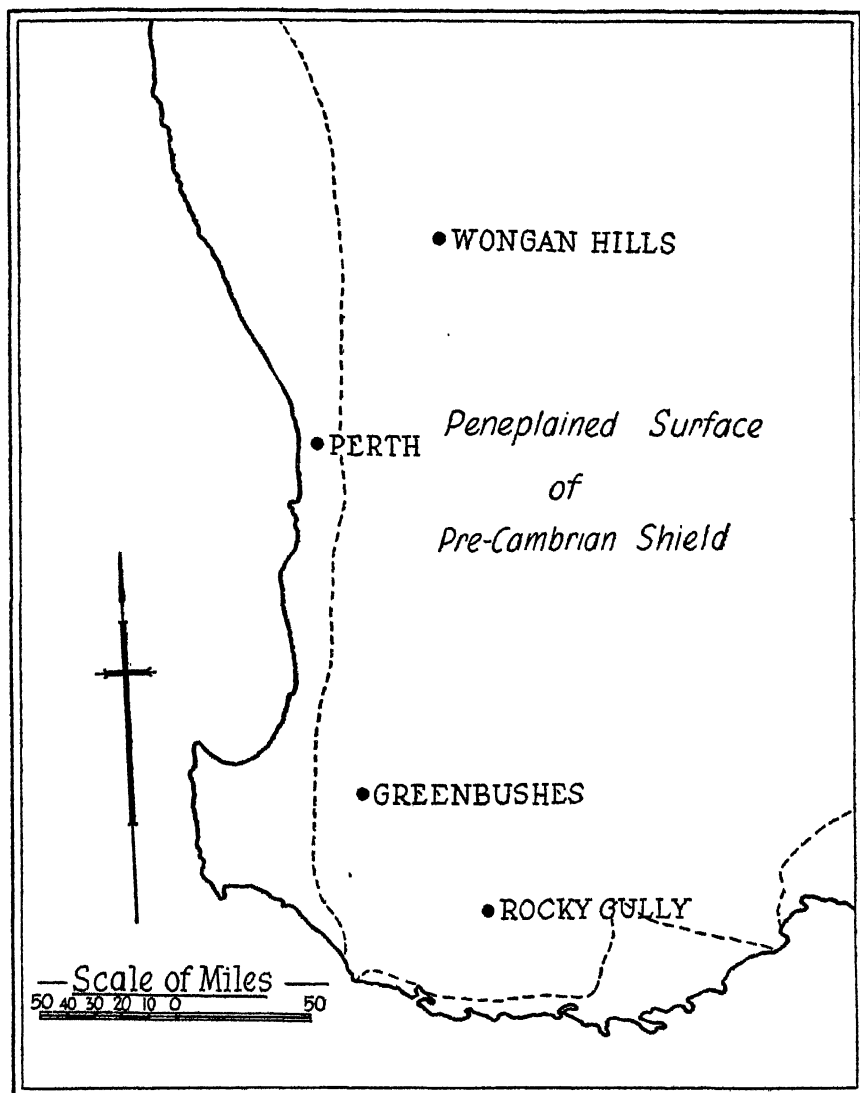


FIG. 1. MAP OF SOUTHWESTERN AUSTRALIA, SHOWING EXTENT OF THE PENEPLAIN ON PRE-CAMBRIAN ROCKS AND POSITIONS OF THE LATERITE PROFILES DESCRIBED

from reddish black to pale yellowish brown. Quartz grains uniform in size (1 to 2 mm.) and coated with iron oxide are set in the mixture. The ferruginous center of the pisolite gives way abruptly to a hard coating, about 1 mm. thick, of a brownish yellow mixture of gibbsite, kaolinite, and small amounts of opaline silica. This, in turn, is surrounded

by a friable material consisting mainly of kaolinite, a little opaline silica, and gibbsite, from which the pisolite parts fairly readily, leaving a rounded cavity. The main body of the matrix contains little gibbsite, being mainly kaolinite with quartz grains and minor quantities of opaline silica. It is pale yellow and friable when freshly broken, but deepens in color to bright yellow after a few days. (Sample 4693/45.)[2]

*At 12 inches.* More or less massive laterite, passing gradually to yellow, softer material with horizontal and vertical reddish brown bands. The structure and composition are very similar to those of the surface fragments, but the laterite is traversed by irregular channels, on the walls of which have been deposited first iron oxides, then gibbsite and kaolinite in a white layer. (Sample 4694/45.)

*At 57 inches.* Mottled lithomarge, yellow and reddish-brown-banded material which is fairly soft. The iron occurs as rusty mottlings in a pale yellow clayey matrix in which small pisolites (up to 5 mm.) are sparingly present. There are some compact masses of iron-stained clay. The matrix consists mainly of kaolinite and gibbsite and is variable in texture. Some parts are fine-textured, pale yellow, and consist of gibbsite with some clay, whereas other parts are coarse-textured, darker yellow, and consist of gibbsite, diaspore, and a little clay. (Sample 4695/45.)

*At 84 inches.* Light gray and reddish brown horizontally banded, fairly soft lithomarge. There are many aggregates of brittle, easily pulverized gray clay bordered with pale yellow material consisting mainly of gibbsite. The iron is unevenly distributed in reddish brown patches in which it is apparently mixed intimately with the clay and gibbsite. (Sample 4696/45.)

*At 120 inches.* Reddish brown, white, and yellow mottled lithomarge or well-weathered rock apparently of granitic type. The texture is coarse throughout, the iron occurring as very small mottlings (1 to 2 mm.) but concentrated into dark shiny masses in places. Aggregates of white clay are also present. The material has the appearance of highly kaolinized granite or gneiss. (Sample 4697/45.)

## Greenbushes

The profile described is situated in an open cut on Mineral Claim 1, about 2 miles south of Greenbushes on the main Bridgetown road. The country is rather heavily mineralized with cassiterite and tantalite, because of which Greenbushes has been a center for sporadic mining of alluvial and lode tin for more than 50 years. The laterite represents the surface of the old peneplain which stands here at approximately 1,000 feet above sea level. At the site sampled, the country rock was not exposed even at a depth of 50 or more feet, but it is known to be a gneissic granite which has been greisenized by the introduction of gases and fluids associated with the mineralization. Tourmaline and muscovite mica are abundant.

*0–24 inches.* Sandy soil with loose gravel. The decemented material, unlike that from Wongan Hills, consists of very hard individual pisolites ranging in size from 1 to 30 mm. Many are almost perfectly spherical. There is no definite coating, but the pisolites are hard and brown, becoming lighter and slightly softer toward the center. They consist of diaspore and kaolinite with iron oxides and perhaps gibbsite. Quartz grains (up to 1 mm.) are distributed throughout. A small quantity of black grains, which may be magnetite, ilmenite, cassiterite, or tourmaline, is often observed. (Sample 342/46.)

*24–60 inches.* Pale brownish yellow friable but compact lithomarge with little structure. The bulk of the material appears to be a mixture of kaolinite and gibbsite with a

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[2] Numbers refer to samples in the collection of the Government Chemical Laboratories.

considerable quantity of quartz and some opaline silica. Patches of black tourmaline are often visible, and some small pisolites occur sporadically. (Sample 343/46).

*60–96 inches.* White kaolinized material, with much white mica in fine to coarse scales, and some segregations of black tourmaline. This layer consists essentially of kaolinite, quartz, and mica. (Sample 344/46.)

*Below 96 inches.* White kaolinized rock showing distinct remains of gneissic structure and bedding. The minerals are the same as in the previous sample. (Sample 345/46.)

## *Rocky Gully*

The samples of this profile were collected in a test pit put down to obtain a type profile of Bangalup gravelly sandy loam on location 1924 about 5 miles east of Frankland River Bridge. Bangalup gravelly sandy loam is a soil developed on the surface of the old peneplain and has been described recently by the Soils Division of the Council of Scientific and Industrial Research during the course of a survey. The country rocks of the area are interbedded gneisses, both acid and basic, intruded by massive granite.

*0–3 inches.* Dark brownish gray sandy loam. (Sample 3675/46.)

*3–16 inches.* Dull brown very gravelly sandy loam with decemented very hard brown pisolites thinly and irregularly coated with material similar in appearance to that on the pisolites in the Wongan Hills profile. The pisolites consist of a mixture of diaspore and kaolinite with iron oxides. A little gibbsite may be present, and there are a considerable amount of quartz and some opaline silica. The centers of some of the pisolites contain white kaolinite. (Sample 3676/46.)

*22–40 inches.* Mottled creamy white clay in which a few pisolites are embedded. The main part of the clay consists of a mixture of kaolinite and gibbsite. A fair amount of quartz and some opaline silica are present. (Sample 3677/46.)

*57–75 inches.* Mottled cream to white and red clay with quartz grit. The material has the appearance of highly kaolinized rock. (Sample 3678/46.)

*75–120 inches.* Mottled cream to white and red gritty clay. There is a higher proportion of grit, mostly as quartz, as the underlying rock is approached, and the material resembles a highly kaolinized rock in texture and general appearance. (Sample 3679/46.)

### CHEMICAL COMPOSITION

The chemical composition of the materials forming the laterite profiles is given in table 1, from which it will be seen that they are all high in silica, a considerable proportion of which is present as free silica (quartz). The analyses are comparable with those of laterite and lithomargic laterite over similar parent rocks in India (4) with respect to silica, alumina, ferric oxide, and combined water. The titania in the profiles described is variable, being concentrated in the pisolites of the Greenbushes profile, noticeably low in the Wongan Hills profile, and high in the Rocky Gully profile. Lime and magnesia are conspicuously absent except in the lower parts of the Rocky Gully profile, which are like the weathered parent rock. In the Greenbushes profile, MgO is present as a constituent of tourmaline (schorl). Alkalies were not determined.

### MINERALOGICAL COMPOSITION

The mineralogical composition of the laterite profiles was determined from a consideration of the chemical analyses of table 1 (no adjustments being made

for errors described under *Chemical Analysis* above) together with optical and other data. It was not possible to obtain dehydration or x-ray data, which are desirable in an investigation of this nature.

The essential minerals of the laterite profiles are clay minerals, quartz, diaspore

TABLE 1

*Chemical composition of laterite profiles from Wongan Hills, Greenbushes, and Rocky Gully*

| Locality | WONGAN HILLS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number | 4693/45 | | 4694/45 | | 4695/45 | | 4696/45 | | 4697/45 | |
| Depth............inches | Surface (pebbles)* | | 12 | | 57 | | 84 | | 120 | |
| | per cent | mols | per cent | mols | per cent | mols | per cent | mols | per cent | mols |
| SiO₂ total | 45.7 | 761 | 44.5 | 741 | 46.2 | 769 | 46.0 | 766 | 52.5 | 874 |
| SiO₂ free | 20.6 | 343 | 18.3 | 305 | 19.0 | 316 | 22.1 | 368 | 24.9 | 414 |
| SiO₂ combined | 25.1 | 418 | 26.2 | 436 | 27.2 | 453 | 23.9 | 398 | 27.6 | 460 |
| Al₂O₃ total | 26.6 | 261 | 29.3 | 288 | 30.9 | 303 | 29.2 | 287 | 25.1 | 246 |
| Al₂O₃ soluble in 5 per cent NaOH | 8.0 | 79 | 10.3 | 101 | 6.3 | 62 | 6.8 | 67 | 6.5 | 64 |
| H₂O combined | 10.59 | 588 | 11.59 | 643 | 12.05 | 669 | 11.46 | 635 | 9.56 | 531 |
| H₂O hygroscopic | 1.10 | 61 | 1.43 | 79 | 1.34 | 74 | 1.66 | 92 | 1.22 | 68 |
| Fe₂O₃ total | 14.4 | 90 | 11.9 | 75 | 8.3 | 52 | 9.5 | 60 | 10.2 | 64 |
| TiO₂ total | 0.64 | 8 | 0.63 | 8 | 0.68 | 9 | 0.78 | 10 | 0.66 | 8 |
| MnO total | 0.011 | | 0.007 | | 0.005 | | 0.012 | | 0.003 | |
| CaO total | 0 or tr. | | 0 or tr. | | 0 or tr. | | 0 or tr. | | 0 or tr. | |
| MgO total | 0 or tr. | | 0 or tr. | | 0 or tr. | | 0 or tr. | | 0 or tr. | |
| P₂O₅ total | tr. | | tr. | | tr. | | tr. | | tr. | |

| Locality | GREENBUSHES | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample Number | 342/46 | | 343/46 | | 344/46 | | 345/46 | |
| Depth............inches | 0–24 (pebbles)* | | 24–60 | | 60–96 | | Below 96 | |
| | per cent | mols | per cent | mols | per cent | mols | per cent | mols |
| SiO₂ total | 28.2 | 469 | 58.0 | 966 | 45.4 | 756 | 52.6 | 875 |
| SiO₂ free | 24.7 | 411 | 48.9 | 815 | 28.7 | 478 | 32.5 | 542 |
| SiO₂ combined | 3.5 | 58 | 9.1 | 151 | 16.7 | 278 | 20.1 | 333 |
| Al₂O₃ total | 38.7 | 380 | 25.3 | 248 | 35.3 | 346 | 32.3 | 317 |
| Al₂O₃ soluble in 5 per cent NaOH | 13.7 | 134 | 19.3 | 189 | 10.2 | 100 | 3.4 | 33 |
| H₂O combined | 8.13 | 451 | 12.06 | 668 | 12.63 | 701 | 10.59 | 587 |
| H₂O hygroscopic | 3.88 | 216 | 0.63 | 35 | 0.93 | 52 | 0.92 | 51 |
| Fe₂O₃ total | 17.6 | 110 | 3.9 | 24 | 3.8 | 24 | 1.5 | 9 |
| TiO₂ total | 1.31 | 16 | 0.62 | 8 | 0.34 | 4 | 0.20 | 3 |
| MnO total | 0.015 | | tr. | | 0.030 | | 0.012 | |
| CaO total | 0 or tr. | | 0 or tr. | | 0 or tr. | | 0 or tr. | |
| MgO total | 0.14 | | 0.07 | | 0.14 | | 0.09 | |
| P₂O₅ total | 0.01 | | 0.20 | | 0.09 | | 0.16 | |

TABLE 1—*Continued*

| Locality.................... | ROCKY GULLY | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample Number.............. | 3676/46 | | 3677/46 | | 3678/46 | | 3679/46 | |
| Depth.................inches | 3–16 (pebbles)* | | 22–40 | | 57–75 | | 75–120 | |
| | *per cent* | *mols* | *per cent* | *mols* | *per cent* | *mols* | *per cent* | *mols* |
| SiO₂ total.............. | 58.7 | 977 | 43.6 | 725 | 48.5 | 808 | 60.0 | 999 |
| SiO₂ free.............. | 50.9 | 848 | 34.5 | 574 | 18.2 | 303 | 42.6 | 709 |
| SiO₂ combined......... | 7.8 | 129 | 9.1 | 151 | 30.3 | 505 | 17.4 | 290 |
| Al₂O₃ total............. | 18.2 | 179 | 33.6 | 330 | 31.1 | 305 | 26.4 | 259 |
| Al₂O₃ soluble in 5 per cent NaOH.......... | 10.4 | 102 | 17.5 | 172 | 6.0 | 59 | 4.7 | 46 |
| H₂O combined......... | 6.70 | 372 | 14.50 | 804 | 11.84 | 657 | 8.86 | 492 |
| H₂O hygroscopic........ | 2.41 | 134 | 1.56 | 87 | 1.89 | 105 | 1.23 | 68 |
| Fe₂O₃ total ............. | 10.7 | 67 | 4.7 | 29 | 4.2 | 26 | 1.8 | 11 |
| TiO₂ total.............. | 1.84 | 23 | 1.31 | 16 | 1.98 | 25 | 1.21 | 15 |
| MnO total.............. | 0.038 | | 0.015 | | 0.077 | | 0.021 | |
| CaO total.............. | 0 or tr. | | 0 or tr. | | 0.13 | | 0.05 | |
| MgO total.............. | 0 or tr. | | 0 or tr. | | 0.17 | | 0.10 | |
| P₂O₅ total.............. | 0.02 | | 0.11 | | 0.06 | | 0.04 | |

\* Decemented pisolites from soil above massive laterite.

and gibbsite, iron-bearing minerals such as turgite (an intimate mixture of goethite and hematite), and hydrous micas.

The accessory minerals are the refractory residual grains from the parent rocks which take no part in the development of the laterite profile. Such minerals are of interest here only insofar as they may be considered indicative of a particular type of parent rock. These minerals can be concentrated by bromoform (sp. gr. 2.8). The heavy residues from the decemented pisolites contain, in addition, iron-bearing minerals such as magnetite and ilmenite, which have largely arisen during laterization and subsequent changes. Table 2 gives the minerals present in the various parts of the profiles.

### Clay minerals

The clay mineral present throughout the profiles appears to be kaolinite (Al₂O₃·2SiO₂·2H₂O), but it is only in the lower parts of the Greenbushes and Rocky Gully profiles that it occurs in typical vermicular crystals with the correct refractive index, birefringence, pleochroism, and extinction angle for kaolinite. In other samples it is in an amorphous form with a refractive index of 1.56+ and sensibly isotropic; it is colorless to pale brownish yellow. The unidentified "clay mineral" in table 2 differs somewhat from typical kaolinite, but it could not be identified with certainty.

### Quartz

Table 2 shows that quartz is present throughout the profiles. The sandy soil immediately above the massive laterite or associated with decemented pisolites consists almost entirely of quartz, but in samples of the lithomarge and kaolinized

rock it is variable in amount. The quartz grains are angular to subangular in shape, but in the surface soil, as has been noted elsewhere, there is a certain proportion of more rounded grains which probably owe their shape to slight solubility of quartz during and subsequent to the laterization processes. Table

TABLE 2

*Mineralogical composition of laterite profiles from Wongan Hills, Greenbushes, and Rocky Gully*

| Locality........ | WONGAN HILLS | | | | | | GREENBUSHES | | | | | ROCKY GULLY | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number. | 4693/45A* | 4693/45B* | 4694/45 | 4695/45 | 4696/45 | 4697/45 | 342/46A | 342/46B | 343/46 | 344/46 | 345/46 | 3675/46A | 3676/46B | 3677/46 | 3678/40 | 3679/46 |
| Depth.....inches | Surface | Surface | 12 | 57 | 84 | 120 | 0–24 | 0–24 | 24–60 | 60–96 | Below 96 | 0–3 | 3–16 | 22–40 | 57–75 | 75–120 |
|  | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent | per cent |
| *Minerals* | | | | | | | | | | | | | | | | |
| Quartz† | 99 | 21 | 18 | 19 | 22 | 25 | 93 | 25 | 49 | 29 | 32 | 96 | 51 | 34 | 18 | 42 |
| Kaolinite | | 53 | 56 | 58 | 51 | 60 | | 8 | 19 | 36 | 42 | | 17 | 20 | 64 | 37 |
| Diaspore }‡ | | + | + | + | + | | | 43 | | | | | 17 | + | | |
| Gibbsite } | | 8 | 11 | 11 | 13 | 3 | | | 26 | 9 | | | + | 38 | 3 | |
| Hydrous mica (a)§ | | | | | | | | | | 20 | 15 | | | | | |
| Hydrous mica (b) | | | | | | | | | | | | | | | 2 | 4 |
| Muscovite | | | | | | | | | | 2 | 10 | | | | | |
| "Clay mineral" | | | | | | | | | | | | | | | 7 | 14 |
| Iron as Fe₂O₃ | | 14 | 12 | 8 | 9 | 10 | | 17 | 4 | 4 | 1 | | 10 | 5 | 4 | 2 |
| Felspar | | | | | | | + | | | | | | | | | |
| *Heavy residue* | 0.4 | 1.3 | 0.1 | 0.3 | 0.1 | 0.2 | 6.5 | 15 | 0.4 | 0.4 | 0.04 | 4 | 9.7 | 1.6 | 3.5 | 1.4 |
| Magnetite | tr. | 0.1 | tr. | tr. | tr. | tr. | n.d.‖ | 8.5 | tr. | tr. | tr. | 0.4 | 4.7 | 0.1 | tr. | tr. |
| Ilmenite | n.d. | 0.2 | | | | | n.d. | 3.0 | | | | n.d. | 1.3 | | | |
| Hematite, etc. | n.d. | n.d. | | | | | | 2.0 | | | | | 2.0 | | | |
| Nonmagnetic | 0.4 | 1.0 | 0.1 | 0.3 | 0.1 | 0.2 | | 1.5 | 0.4 | 0.4 | 0.04 | 3.0 | 1.7 | 1.5 | 3.5 | 1.4 |

\* A = sand or sandy soil; B = pebbles in surface sand or sandy soil.
† The figures for quartz include small quantities of opaline silica.
‡ See text for method of tabulation.
§ See text for distinguishing characteristics of hydrous mica (a) and (b).
‖ n.d. = not determined.

3 gives the grading of these sands, which do not appear very different from sandy soils normally developed over granitic rocks.

### Diaspore and gibbsite

No crystals of either diaspore ($Al_2O_3 \cdot H_2O$) or gibbsite ($Al_2O_3 \cdot 3H_2O$) were seen under the microscope, but their presence is inferred from the chemical

analyses, and from the occurrence of yellowish brown grains with higher refractive index among the clay minerals. In the heavy residues, in which diaspore should be present, only a small quantity of a yellowish brown mineral is found after treatment with HCl, and this is probably diaspore, but it is not present in sufficient quantity to satisfy the composition as shown in table 1. Absence from the heavy residues is probably due to its intimate mixture with gibbsite. The data indicate that gibbsite is always mixed with some diaspore. In table 2 gibbsite and diaspore are bracketed, the total percentage of aluminum hydrates being placed opposite the more prominent of the two; the presence of the aluminum hydrate of smaller quantity is indicated by a plus sign. It is noticeable that there is a very considerable amount of diaspore in the pisolites of the Greenbushes profile. The reason for this concentration is not apparent.

TABLE 3

*Grading of surface sandy soils overlying laterite*

| GRADING | | WONGAN HILLS SURFACE | GREENBUSHES 0-24 inches | ROCKY GULLY 0-3 inches |
|---|---|---|---|---|
| Sieves* retaining particles | Sizes of openings in sieve | | | |
| | *mm.* | *per cent* | *per cent* | *per cent* |
| 9 | 1.98 | n.d.† | n.d. | n.d. |
| 16 | 0.99 | 3.0 | 12.1‡ | 2.9 |
| 32 | 0.49 | 28.8 | 18.4 | 15.7 |
| 60 | 0.24 | 30.1 | 21.4 | 22.2 |
| 115 | 0.12 | 18.3 | 22.8 | 35.2 |
| 250 | 0.06 | 9.7 | 14.8 | 14.8 |
| −250 | | 10.1 | 10.5 | 9.2 |

* Tyler standard sieves; samples sieved mechanically for 15 minutes.
† n.d. = not determined.
‡ Contains small pisolites in addition to quartz grains.

## Iron oxides

The color of various parts of the laterite profiles is almost entirely due to the intimate mixing of iron oxides in a colloidal form, which is readily seen microscopically to be incorporated in clay minerals, diaspore, and gibbsite. The color can be reduced or removed by acid treatment. Turgite appears to be the principal iron constituent in the Wongan Hills profile, which contains very little magnetite (see table 2). In the other two profiles, magnetite is plentiful in the pisolites and, together with ilmenite and hematite, accounts for all but 3 or 4 per cent of the $Fe_2O_3$. In the lower parts of these profiles the iron content of the heavy residues is much smaller, with only a trace of magnetite. This still leaving, therefore, a small percentage of iron in colloidal form. It is probable that ferrous oxide is present in the matrix of the Wongan Hills massive laterite, which darkens when split open and exposed to the air.

## Hydrous micas

Two distinct varieties of a mineral here described as "hydrous mica," following Hendricks and Alexander (9), occur. They are designated *a* and *b* in table 2.

Hydrous mica $a$ is found in the lowest parts of the Greenbushes profile; $b$ in the same position in the Rocky Gully profile.  Form $a$ is an isotropic, colorless mineral with a platy habit very similar to that of muscovite, from which it differs in having a somewhat lower refractive index.  Muscovite flakes giving well-defined biaxial negative interference figures are fairly plentiful in these samples, and it seems probable that $a$ is similar to Ross and Kerr's "muscovite-like kaolin mineral" (16, p. 172).  Form $b$ occurs in flat plates, often with straight edges and characterized by regularly arranged rod-like inclusions, which are probably rutile or leucoxene.  These inclusions are arranged at angles of 66° to one another, simulating the inclusions common to micas which are arranged in the directions of the percussion figure.  The plates are isotropic and have a refractive index of 1.56±.  Although not a distinct mineral, $b$ suggests derivation from biotite mica, as the deposition of titania is one of the first changes caused by weathering that is noticeable in biotite.  All samples of biotite from various Western Australia granites show a small percentage of titania.  Hydrous mica $b$ appears to be similar to the altered mica described by Denison et al. (3, pp. 23–24). The only other mineral which shows a similar arrangement of inclusions is gibbsite, but no interference figures were obtainable, and the small quantity of MgO present suggests a mica.

### Accessory minerals

The minerals of the heavy residues are nonessential so far as the laterization process is concerned, except where the parent rock contains a large proportion of ferromagnesian minerals which would influence the minerals subsequently formed. The ratio of zircon present in the lowest horizon to that in the surface soil will give some indication of the amount of material removed during laterization, but this factor must be used with caution for igneous and metamorphic rocks the heavy mineral content of which may be more variable than that of individual beds of sedimentary rocks.  The use of zircon for this purpose has been suggested by Haseman and Marshall (8).

The following nonmagnetic heavy minerals are present in these profiles:

*Wongan Hills*—zircon, amphibole, epidote, tourmaline, rutile, andalusite.
*Greenbushes*—tourmaline, cassiterite, zircon, kyanite, rutile, tantalite, stibiotantalite.
*Rocky Gully*—zircon, amphibole, epidote, rutile, sillimanite, tourmaline, spinel, monazite.

It is noteworthy that the surface sandy soil contains a much larger amount of heavy residue than the samples from the lower parts of the profiles which are kaolinized rocks at Greenbushes and Rocky Gully.  The Wongan Hills profile contains approximately the same amount of heavy residue throughout.  (See table 2.)

### DISCUSSION

It has long been recognized that laterites in Western Australia were formed during a previous geological age under different climatic conditions.  These

laterites are now removed from the zone of laterization as a result of uplift and change of climatic conditions, and the present location with regard to ground-water is comparable to that of Campbell's "dead laterite" (1, p. 74), a fact realized by Jutson (10) and Prescott (13). In the arid interior of the southern part of this state, complete fossil laterite profiles occur under sand-plains, but where a new cycle of erosion has been initiated the profiles are in various stages of truncation. There are several stages in the disintegration of a laterite profile. First, the matrix of the massive laterite is removed to form isolated groups of pisolites, which during cementation may become coated by deposition from leaching solutions, as in the surface of the Wongan Hills material. The sand in the uppermost horizon is most probably residual from the disintegration of the underlying massive laterite. The next stage involves the further removal of material from the fragments isolating the individual pisolites. Subsequently, the remainder of the massive laterite is removed, leaving the lithomarge overlain by sand and residual pisolites which consist essentially of the hardened core of the original pisolites. The lithomarge also seems to be reduced in thickness, so that in actual fact the sandy surface soil lies relatively close to the kaolinized rock beneath. This removal of material on gently undulating surfaces appears to have taken place by leaching, particularly by removal of iron, in contrast to the more active processes of erosion which are evident at the broken edges of the peneplain and result in cliffs and "breakaways." This gradual reduction means that, in part at least, the soils of the present cycle are being formed from the kaolinized but not laterized underlying rock, a fact which is being recognized by soil surveyors.

A point suggested by the chemical and mineralogical analyses is that the presence of diaspore (or amorphous aluminum hydrate) in the surface layers may be due to partial desiccation of gibbsite during a very arid hot period following the humid climate under which the laterite originally formed. Such an arid period has been recognized in many parts of Australia (2, 18). Some information concerning the distribution of gibbsite and diaspore in Western Australia laterites may help in an understanding of their mode of origin.

Table 2 gives the distribution of gibbsite and diaspore in the profiles. In the disintegration and redistribution of the materials of the Wongan Hills profile, about 10 per cent of the clay materials consist of gibbsite which will have some influence on the base-exchange capacity of the resulting soil. In both the Green-bushes and Rocky Gully profiles there is a concentration of gibbsite in the litho-marge horizon. This examination, therefore, gives a much clearer picture of minerals likely to be present in the silt and clay grades of soils of this type than do the standard soil mechanical analysis and chemical analysis. The presence of gibbsite and/or diaspore will have considerable significance in determining the origin of many soils in the agricultural areas of Southwestern Australia where it is becoming increasingly evident that parent material is of particular importance. Because of recent geological history, most of the soils are residual from the underlying rock, whether this has suffered laterization or is now weathering to produce soils normal to the present climatic conditions.

The presence of MgO and CaO, together with the remains of original minerals of the parent rocks, in the lower parts of the Rocky Gully profile and to a certain extent in the Greenbushes profile indicates that the materials are incompletely leached, and that when incorporated in new soils forming from these profiles they should be more fertile than those arising from the upper parts of the profiles which contain gibbsite or diaspore. Recognizable mica and its alteration products indicate that probably some other constituents, such as potash, also remain. There is still some reserve supply of mineral matter available for plant-food (11). A soil is considered to be infertile when this reserve supply is used up or removed as, for example, in the sandy soils overlying laterite profiles in the sand-plains.

CONCLUSIONS

The chemical and mineralogical data of three typical laterite profiles developed on granitic rocks serve to indicate the changes that have taken place as a result of laterization during a previous geological period and subsequently due to present climatic conditions whereby the lateritic materials are becoming the parent materials of new soils. An application of the methods of examination outlined appears to be a useful approach to the study of Western Australia soils in general, as well as those of lateritic origin or containing lateritic material. It has generally been considered that soils formed on laterites are infertile (11, 12), but this need not necessarily apply to soils derived from laterites in the advanced stages of truncation where there is a transition to the normal soils formed currently and utilizing the kaolinized rock as a C horizon. A knowledge of the minerals present in the various horizons of laterite profiles should be helpful in assessing the characteristics of the clay fractions of these soils and of any in which lateritic material is incorporated.

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# USE OF RADIOACTIVE PHOSPHORUS IN A STUDY OF THE AVAILABILITY OF PHOSPHORUS TO GRAPE VINES UNDER FIELD CONDITIONS[1]

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One of the methods in current use for estimating availability of plant nutrients in a soil depends on a chemical examination of the plant itself rather than of the soil. The method involves the chemical analysis of selected plant parts collected at specific intervals during the growing season. The hypothesis upon which the procedure is based is that, for a given part of the plant, critical nutrient concentrations can be established below which the plant is deficient in nutrients and above which the plant is adequately supplied. The general applicability of this method is still under investigation.

In the present research the availability of phosphate was investigated through the method of plant analysis. In addition, the technique was amplified by the use of radioactive phosphorus. With this innovation it was expected that subsequent examinations of selected parts of the plant for radioactivity, along with the chemical analysis of the parts, would give information as to the availability to the plant of phosphate in the soil as well as of the relative efficiency of two methods of phosphate application.

In California, the efficient application of phosphorus to crops has been of prime importance on some soils because of their high fixing power for phosphate in direct competition with the plants growing therein. This fixing of soluble phosphates in an unavailable form is an outstanding property of soils characterized by the presence of kaolinic clay such as those related to the Aiken series (3). Though responses to the application of soluble phosphorus can be readily obtained on these soils with annual crops both in pot experiments (3) and in the field (2), no consistent increases in yield from phosphorus applied to mature tree or vine crops have been reported to date (2). At times during the growing season significant but relatively small increases in phosphate concentrations have been observed in petioles of grape vines from plots fertilized with 400 to 620 pounds of $P_2O_5$ per acre.[2] None of the small increases in phosphate concentrations of the vines have consistently increased the yields, however, even though the phosphate concentrations in the vines were exceedingly low early in the growing season. The failure to increase the yields of grapes on vines very low in phosphorus, as shown by leaf analysis, has led to the conclusion that even though the vines are comparatively low in phosphorus, the amounts are still adequate for satisfactory growth; if this conclusion is not accepted, it has been suggested that the amounts applied have been inadequate in competition

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[2] Unpublished data.

with the soil or that the fertilizers applied were placed incorrectly in relation to the active roots of the vines. It was the purpose of this experiment to study, with the aid of radioactive phosphorus, the merits of the latter possibilities as causes for failures in experiments with phosphorus on grape vines.

<div align="center">PROCEDURE</div>

The grape vines selected for the experiment were of the Burger variety grafted on resistant rootstock and were in the Fountain Grove vineyard just north of Santa Rosa, California. These vines were approximately 25 years old and during their lifetime had been making fair growth. The soil on which the vines were growing was a red loam typical of the soils in the Aiken group, and, to date, had not received phosphate fertilizers. Responses to phosphate applications have been obtained on this soil with lettuce grown in pots in the greenhouse and with cover crops in the field, but no responses either in 1945 or 1946 were observed with vines adjacent to those of the present experiment, even though 2 pounds of treble superphosphate per vine (620 pounds $P_2O_5$ per acre) were applied in December, 1944.

On May 13, 1946, the grape vines of the experiment were treated with radioactive phosphorus. This was accomplished by building a ridge of soil in the shape of a square 6 to 8 inches high and 2 feet from the base of each vine (fig. 1). In each basin of the D-series (deep placement), a hole $1\frac{1}{2}$ inches wide and 15 inches deep was drilled near each corner of the square. A total of 640 ml. of a phosphoric acid solution "tagged" with radioactive phosphorus ($P^{32}$) containing 0.86 pound of $P_2O_5$ (170 gm. of phosphorus) was distributed in equal portions to the four holes around the single vine. Immediately thereafter, 40 gallons of water, equivalent to a 4-inch rain, was added to each vine. In the S-series (surface application) 10 gallons of water was added first and was immediately followed with 5 gallons of water containing the radioactive phosphorus. When the solutions had penetrated the soil, the remaining 25 gallons of water was added. The single vine of the D'-series was treated as were the vines in the D-series, except here the vine received a total of only 1.63 gm. of phosphorus (0.0082 pound $P_2O_5$), the specific activity of which was approximately 200 times greater than that used in the other treatments. The three vines in the C-series, which served as a control, were each treated with 40 gallons of water. After the water had entered the soil in each basin, it was covered with dry soil to prevent contamination of the leaves by dust-borne radioactive phosphorus. At the time of application, the activity of the phosphate solutions was such that the 170-gm. sample gave 1.79 $\times$ 10$^4$ counts per minute per milligram of phosphorus and the 1.63-gm. sample used in the D' application gave 3.72 $\times$ 10$^6$ counts per minute per milligram of phosphorus.

The first plant samples were collected just prior to application of the fertilizers at 4 p.m. May 13, 1946, and a second lot of samples was collected at 8 a.m. May 15, just 40 hours after application of the phosphoric acid containing the radioactive phosphorus. Samples were again collected on May 24, June 25, July 22, August 28, and October 23. Only the samples taken on the May 15 (40 hours)

and 24 (11 days) and on June 25 (43 days) were assayed for radioactivity. Samples taken after the 43-day period were not assayed, since the activities had decayed to too low a value for accurate counts. The plant parts collected con-
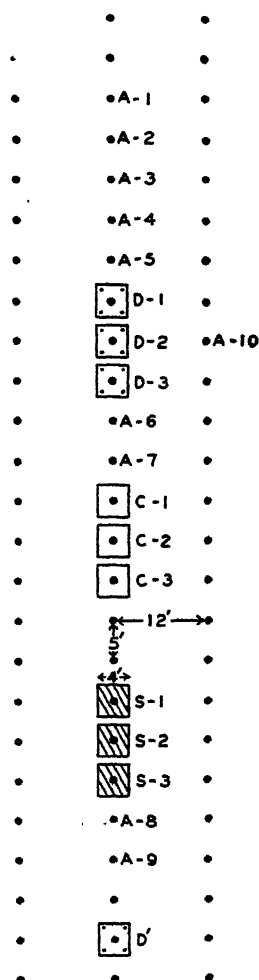


FIG. 1. PLOT DIAGRAM OF GRAPE VINE EXPERIMENT

The larger black dots represent grape vines; the smaller dots indicate holes 1½ inches in diameter and 15 inches deep; and the squares are 4- by 4-foot ridges of soil built to hold 40 gallons of water. The vines in the S-series were treated with phosphoric acid containing radioactive phosphorus as a surface application; those in the D-series, with the same amounts as a deep application; and the C-series, with water only. The D'-vine was treated with radioactive phosphorus only. The vines in the A-series were untreated.

sisted of the apexes (the first 8 inches at the end of the canes), the entire bunches of immature grapes from these canes, the petioles from the "youngest mature" leaf near the end of the cane, and the blades from these leaves.

After collection of the samples, the blades and apexes were washed in a weak acid solution (0.2$N$ HCl) and then dried in an oven at 55° C.  Washings of the leaves proved the absence of contamination from radioactive dust.  After the plant materials were dry, they were ground to pass a 40-mesh sieve.  Thereafter, analyses were made for radioactive phosphorus, phosphates soluble in 2 per cent acetic acid (5), and total phosphorus (5).  All values are expressed in parts per million of dry plant material.

Soil samples were collected on May 24 and on June 25 from one of the areas that received the surface application of phosphoric acid (vine S-3).  These samples were taken by digging a trench to a depth of 20 inches so that the vertical wall closest to the vine was 15 and 11 inches respectively, from its trunk.  From

TABLE 1

*Radioactive analyses of grape vine parts*

Expressed on dry basis in parts per million of added phosphorus

| TREATMENTS* | MAY 15 (40 hours) | MAY 24 (11 days) | JUNE 25 (43 days) | MAY 15 (40 hours) | MAY 24 (11 days) | JUNE 25 (43 days) |
|---|---|---|---|---|---|---|
| | | *Apexes* | | | *Blades* | |
| D | 28.2 | 225 | 386 | 71 | 56 | 156 |
| C | 0 | 0 | 0 | 0 | 0 | 0 |
| S | 3.4 | 111 | 169 | 5.9 | 23 | 95 |
| D' | 0 | 0.17 | ... | trace | 0.04 | ... |
| | | *Petioles* | | | *Bunches* | |
| D | 62 | 56 | 168 | 14.5 | 105 | 219 |
| C | 0 | 0 | 0 | 0 | 0 | 0 |
| S | 0 | 30 | 87 | 0 | 35 | 169 |
| D' | 0 | 0.10 | ... | 0 | 0.09 | ... |

\* Treatments applied at 4 p.m. on May 13, 1946, were as follows:

   D = deep application of phosphoric acid,
   C = control with water only,
   S = surface application of phosphoric acid,
   D' = deep application, with twice the radioactivity, but without phosphoric acid as a carrier.

the vertical wall, soil samples at intervals of 1 inch for the first 12 inches, and again at the 18-inch level, were carefully removed to avoid contamination from the soils above.  All radioactive measurements were made with a Geiger-Müller counter, using a bell type mica window counter tube.  The weight of the plant samples assayed varied from 0.15 to 4.5 gm.  The weights of the soil samples were from 0.5 to 2.0 gm.  The results tabulated have been corrected for mass absorption and decay, and are expressed as parts per million of added phosphorus (labelled phosphorus) in the dried soils and plant material.

### EXPERIMENTAL RESULTS

*Radioactive analysis of plant samples*

Results of radioactive analyses of the plant samples collected on May 15, May 24, and June 25, are given in table 1.  The results for May 15 show that

when the phosphoric acid was applied by the deep method (D-series), radio-active phosphorus had been absorbed by the roots within the 40-hour period and had moved into the apexes of the canes, into the immature bunches of grapes, and into the blades and petioles of the youngest "mature" leaves. When the phosphoric acid was applied to the soil surface (S-series), however, only the apexes and blades contained enough radioactive phosphorus to be above the background count. When 1.63 gm. of phosphorus (one-hundredth the amount used in the D- and S-treatments) was added by means of the deep application, the blades alone of all the parts tested showed a detectable amount of radio-activity, and this activity was only slightly above the background count.

On the basis of the foregoing observations, the deep application of 170 gm. of phosphorus was more effective in getting phosphorus into the vines than the corresponding amount applied to the soil surface. The lower radioactivity

TABLE 2

*Radioactivity of parts from individual grape vines on May 24 (11 days after fertilization)*
Values expressed on the dry basis as parts per million of added phosphorus

| VINE* | APEXES | PETIOLES | BLADES | BUNCHES |
|-------|--------|----------|--------|---------|
| D-1 | 181.0 | 44.8 | 45.8 | 71.7 |
| D-2 | 442.0 | 109.0 | 109.0 | 229.0 |
| D-3 | 50.6 | 13.6 | 12.8 | 15.6 |
| C-1 | 0 | 0 | 0 | 0 |
| C-2 | 0 | 0 | 0 | 0 |
| C-3 | 0 | 0 | 0 | 0 |
| S-1 | 85.0 | 34.5 | 26.9 | 23.8 |
| S-2 | 158.0 | 35.2 | 29.9 | 49.3 |
| S-3 | 91.2 | 19.7 | 11.9 | 31.4 |
| D' | 0.17 | 0.10 | 0.04 | 0.09 |

* See figure 1 and footnote to table 1.

within the plant parts for the surface application at the end of 40 hours was probably caused by a greater time lag in getting the phosphorus into the root zone and by a greater fixing of the phosphorus in an unavailable form by the soil. The latter possibility is supported by the lack of radioactivity in the vines when treated with smaller amounts of phosphorus (treatment D'; 1.63 gm. of phosphorus). Evidently, in this instance, most of the phosphorus was fixed by the soil and therefore became unavailable to the vines.

On May 24, 11 days after application of the fertilizers, many individual plant samples were taken from the vines in order to discover the distribution of phosphorus within a given vine and to determine the degree of absorption of the radioactive phosphorus by neighboring vines. The activities found within the plant parts for the individual vines are presented in table 2.

From May 15 to 24, the average radioactivity had increased in the apexes and bunches under all phosphorus treatments, while slight decreases occurred

in the petioles and blades of the D-series. The highest activities occurred in the apexes of the canes, followed by considerably lower concentrations in the bunches and still lower levels in the petioles and blades. A study of the data for a given plant part (table 2) shows a large variation in activity between the individual vines under the same treatment. The greatest variation is apparently associated with the vines receiving the phosphoric acid by the method of deep placement. This extreme variation may be attributed to the fact that the fertilizer was distributed in only four holes around the vine and consequently the chance of drilling into zones with active roots depends upon the root distribution of the individual plant, whereas in the surface application the opportunity for uniform contact with roots that may happen to be near the soil surface should be relatively good. In spite of the few holes around each vine, the phosphorus taken up, as determined by the radioactivity, is approximately twice as great for the corresponding plant parts for the deep placement as for the surface application. This difference in radioactivity in favor of the deep placement also held true for the sampling on June 25, even though the phosphorus concentrations in the corresponding plant parts increased markedly (table 1).

Another point of considerable interest is the failure of neighboring vines to contain radioactive phosphorus in any of the parts sampled even though some of the vines tested were only 3 to 4 feet from the point of fertilizer application (fig. 1, vines A-5, A-6, A-8). Evidently the roots of these vines are so distributed as to be unable to absorb phosphorus except in their own immediate vicinity. Vines in other localities, however, have absorbed nitrogen and potash even though the materials were applied all in one spot equidistant from four vines.[3] In the present experiment, inspection at the end of the growing season disclosed that the roots were irregularly distributed about the vine (fig. 2), and furthermore, it was estimated that 90 per cent of the roots were within a radius of 2 feet of the base. Even though some of the lateral roots had a diameter of 1 inch at a distance of only 1 foot from the base of the vine, they had failed to exceed 28 inches in length. The smaller roots from the laterals were also relatively short. One large lateral root was at a depth of 8 inches while another was at the 14-inch level. All of these observations are sufficient within themselves to account for the failure of adjacent vines to absorb the radioactive phosphorus applied to the soil.

### Chemical analysis of plant samples

All the plant samples collected during the season were analyzed for soluble and total phosphorus. The values for the petioles on all sampling dates are reported in table 3, whereas the corresponding results for the apexes, blades, and bunches are reported only for May 24 (tables 4 and 5) because the phosphorus relationships at other times were the same as those observed for this date.

The analytical data indicate that, as a rule, the petioles from the vines fertilized with phosphorus are higher in phosphorus than those from the control

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[3] Unpublished data obtained in this laboratory.

plants (table 3). The differences in favor of the fertilized vines are of questionable significance, especially when the fact is noted that the phosphorus concentration of the vines in the D-series was considerably higher prior to treatment than was that of the control vines.
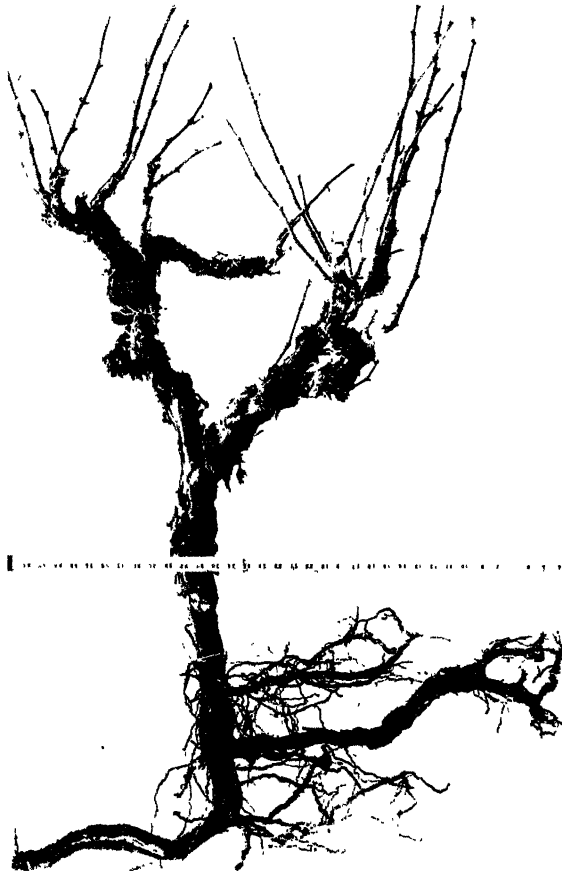


FIG. 2. VINE S-3, TYPICAL OF THE SHORT, RELATIVELY SHALLOW ROOTS OF VINES IN THIS EXPERIMENT
The yardstick is at the ground level

In contrast to the results from the chemical analyses, radioactive counts of the fertilized vines were far above the background counts, while those of the control were equal to those of the background, i.e. had 0 increases (tables 1 and 2). This gave positive proof that the applied phosphorus had been absorbed by the vines. For conclusive evidence of phosphorus absorption through the use of chemical methods, the treatments must be replicated according to the statistical rules (4). Under the present conditions, this would involve consider-

TABLE 3

*Total and soluble phosphorus in petioles of grape during 1946*

Values expressed on the dry basis in parts per million

| TREATMENT* | MAY 13 4 p.m. (initial) | MAY 15 8 a.m. (40 hours) | MAY 24 (11 days) | JUNE 25 (43 days) | JULY 22 (70 days) | AUG. 28 (107 days) | OCT. 23 (163 days) |
|---|---|---|---|---|---|---|---|
| | | | *Total phosphorus* | | | | |
| D | 2120 | 2130 | 1590 | 1140 | 670 | 495 | 400 |
| C | 1690 | 1500 | 1510 | 900 | 610 | 495 | 400 |
| S | 1780 | 1740 | 1650 | 1040 | 610 | 510 | 400 |
| D' | .. | 1450 | 1550 | ... | 670 | ... | 465 |
| | | | *Soluble phosphorus* | | | | |
| D | 870 | 580 | 620 | 490 | 179 | 91 | 88 |
| C | 438 | 389 | 420 | 334 | 146 | 91 | 88 |
| S | 479 | 381 | 550 | 493 | 219 | 99 | 96 |
| D' | ... | 275 | 530 | ... | 203 | .. | 80 |

\* See footnote to table 1.

TABLE 4

*Phosphate extracted by 2 per cent acetic acid from oven-dried grape plant parts collected May 24*

*(11 days after fertilization)*

Values expressed in parts per million of phosphorus

| | | | | |
|---|---|---|---|---|
| D-1 | 1730 | 640 | 492 | 1620 |
| D-2 | 1660 | 750 | 570 | 1640 |
| D-3 | 1690 | 468 | 420 | 1380 |
| Average | 1690 | 620 | 494 | 1550 |
| C-1 | 1390 | 443 | 443 | 1160 |
| C-2 | 1500 | 460 | 418 | 1390 |
| C-3 | 1410 | 355 | 371 | 1000 |
| Average | 1430 | 420 | 411 | 1180 |
| S-1 | 1680 | 600 | 485 | 1490 |
| S-2 | 1760 | 500 | 468 | 1130 |
| S-3 | 1590 | 550 | 452 | 1160 |
| Average | 1680 | 550 | 468 | 1260 |
| D' | 1210 | 530 | 266 | .... |

\* See figure 1 and footnote to table 1.

able work because the phosphorus increases as shown by the radioactive counts are less than 10 and 5 per cent of the soluble and total phosphorus present in

TABLE 5

*Total phosphorus in oven-dried grape plant parts collected on May 24 (11 days after fertilization)*

Values expressed in parts per million of phosphorus

| VINE* | APEXES | PETIOLES | BLADES | BUNCHES |
|---|---|---|---|---|
| D-1 | 4870 | 1480 | 2010 | 3940 |
| D-2 | 5100 | 1750 | 2260 | 3990 |
| D-3 | 4900 | 1550 | 2090 | 3530 |
| Average | 4960 | 1590 | 2180 | 3820 |
| C-1 | 4420 | 1480 | 1850 | 3420 |
| C-2 | 4550 | 1900 | 1900 | 3300 |
| C-3 | 4830 | 1140 | 1640 | 3510 |
| Average | 4600 | 1510 | 1780 | 3410 |
| S-1 | 5100 | 1730 | 2170 | 4030 |
| S-2 | 5400 | 1600 | 2010 | 3510 |
| S-3 | 5000 | 1620 | 1950 | 3600 |
| Average | 5170 | 1650 | 2040 | 3710 |
| D' | 4250 | 1550 | 1950 | 3380 |

\* See figure 1 and footnote to table 1.

TABLE 6

*Penetration of phosphorus applied to the soil surface as determined by radioactive analysis*

PHOSPHORUS IN SOIL

| SOIL DEPTH | May 24 (11 days) | | June 25, 1946 (43 days) | |
|---|---|---|---|---|
| (inches) | p.p.m.* | per cent* | p.p.m.* | per cent* |
| 0–1 | 803 | 11.1 | 2,100 | 33.1 |
| 1–2 | 2,480 | 34.2 | 1,610 | 25.4 |
| 2–3 | 1,430 | 19.7 | 756 | 11.9 |
| 3–4 | 1,150 | 15.8 | 289 | 4.6 |
| 4–5 | 832 | 11.5 | 394 | 6.2 |
| 5–6 | 510 | 7.0 | 321 | 5.1 |
| 6–7 | 32 | 0.4 | 249 | 3.9 |
| 7–8 | 11 | 0.2 | 167 | 2.6 |
| 8–9 | 9 | 0.1 | 195 | 3.1 |
| 9–10 | 0 | 0.0 | 145 | 2.3 |
| 10–11 | 0 | 0.0 | 75 | 1.2 |
| 11–12 | 0 | 0.0 | 24 | 0.4 |
| 12–13 | ..... | .... | 13 | 0.2 |
| 17–18 | 3 | 0.03 | 0 | 0.0 |

' Of added P.

the vines. Such small differences would require many replications to detect phosphorus increases that are statistically significant.

### Radioactive analysis of soil samples

The radioactivities of the soil samples taken adjacent to vine S-3 of the surface application are given in table 6. The figures indicate that 99 per cent of the added phosphorus was located in the first 6 inches of soil on May 24 (11 days) and 86 per cent was in the corresponding zone on June 25 (43 days). Since the water applied was observed to have penetrated at least 20 inches, the failure of phosphorus to follow the movement of the water must reflect the phosphorus-fixing power of the soil, which in this case must be great, since the application when calculated to an area basis was slightly more than 2,300 pounds of $P_2O_5$ per acre. This lack of movement of the phosphate into the soil may account in part for the failure of adjacent vines to absorb phosphorus, even though some of them were within 3 feet of the point of fertilization.

#### DISCUSSION

The present experiments demonstrate the special advantages of using a radioactively labelled element in availability studies. When the chemical analyses of plant parts were supplemented by radioactive analyses, the latter yielded information not otherwise readily obtainable. For example, the radioactive analyses show that for both surface and deep applications, the applied phosphorus appeared in the aerial parts of the plant within 40 hours. At no time throughout these experiments was it possible, however, to observe significant increases by chemical means. To demonstrate differences solely by chemical methods would require many replications of each treatment.

The data give definitive information concerning the efficacy of the different phosphorus applications. In this soil, small amounts of added phosphorus are relatively unavailable to the plant. In the deep application of 1.63 gm. phosphorus, scarcely a trace of the added phosphorus was found in the vine. The data show that even large amounts of phosphorus are not effective unless placed within a foot or two of these vines. When 170 gm. of phosphorus was applied at a depth and to the surface, vines about 4 feet distant from the point of phosphate application showed no detectable amounts of radioactivity. The explanation for this finding was apparent upon examination of the root system of a vine. The root system was found to be relatively shallow, the bulk of the roots occurring at about the 1-foot level. Also, the roots were irregularly distributed and greatly restricted in number and length. The major portion of the roots was within 2 feet of the vine. Since radioactive isotopes can be applied to any point in the soil and subsequently traced to specific plants having roots within the zone of application, a ready means of determining the foregoing characteristics of root distribution in the field was provided.

In this soil, phosphorus migrates slowly. Eleven days after the surface application, the phosphorus had moved in a front to a depth of approximately 6 inches. Thirty-two days later, the phosphorus front had moved approxi--

mately 5 inches deeper. This movement was not dependent on the movement of water, since the latter had penetrated to a depth of at least 20 inches shortly after the application. This slow migration resulted in a reduced effectiveness of the surface applications as compared with the deep applications. In general, because of the high fixation and slow migration of phosphorus in this soil, fertilizations must be made in the immediate zone of the roots in order to be effective. From these experiments, however, it would appear that even large applications of phosphorus under optimum conditions to this particular soil would not lead to marked phosphorus increases in the plants. In the present instance, the maximum uptake of added phosphorus in the aerial portion of the vine was calculated to be less than 1 per cent, even though the phosphorus was applied at a rate of 2,300 pounds $P_2O_5$ per acre.

In conformity with results with tomato obtained by Arnon, Stout, and Sipos (1), the added phosphorus in the vines occurred in the most rapidly growing parts of the plant. So far as the aerial part of the vine is concerned, the highest concentrations were in the apex and, to a lesser degree, in the bunches of young grapes.

The fact that the use of radioactive phosphorus in a field experiment has yielded information not otherwise readily obtainable suggests that this general technique can be applied with profit to other fertilizer problems. Many of the micronutrients as well as sulfur and phosphorus lend themselves well to this type of experimentation because of the long half-lives of their radioactive isotopes. Radio sodium and potassium, even though possessing short half-lives, can be produced in large enough quantities to enable their use in short-term experiments.

## SUMMARY

Phosphoric acid tagged with radioactive phosphorus was applied by two methods (to the surface and at a depth) to a loam soil with a high phosphate-fixing power, and which supported grape vines low in soluble phosphorus. The radioactive analysis of the plant samples of the deep placement indicated that small amounts of phosphate were taken up and translocated throughout the vines (apexes, blades, petioles, bunches) within 40 hours after the phosphoric acid was applied, whereas vines receiving the surface application had relatively small radioactivities in the blades and apexes of the canes. At the 11- and 43-day periods, vines of the deep placement showed phosphorus increases that were approximately twice those of the surface application. These increases were on the order of 5 to 10 per cent of the total and soluble phosphorus present in the vine parts and accordingly were too small to be detected solely by chemical means without many replications of each treatment. Calculations based on the radioactive measurements indicated that less than 1 per cent of the phosphorus added to the soil was contained in the aerial part of the vines. Radioactive analysis of the soils showed that the phosphoric acid, which was applied to the soil surface at the rate of 2,300 pounds per acre of $P_2O_5$, had penetrated 11 inches in 43 days while the water had penetrated at least 20

inches.   Of the phosphorus added to the soil surface 99 per cent and 86 per cent were in the first 6 inches of the profile after 11 and 43 days, respectively.   Radioactive measurements of plant samples from vines only 3 to 4 feet from the point of fertilization indicated there were no active roots at even this short distance. Subsequent removal of the soil from the vines revealed that the roots were localized about the vines and that they were irregularly distributed in the soil.

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# STATUS OF ZINC IN RELATION TO OREGON SOIL FERTILITY[1]

## W. L. POWERS AND T. S. PANG[2]

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An inadequate supply of available zinc was indicated for some Oregon soil types when soil from eight regions of the state were included in trials with minor elements beginning in 1928. Planthouse and field plot trials have subsequently included some 26 soil series and two dozen kinds of field and horticultural crops and hundreds of zinc determinations.

Studies herein reported were planned to determine more about the adequacy of available zinc in certain Oregon soils, the optimum and critical concentrations in relation to crop requirements, and the distribution and effects in plants.

Following the work of Chandler, reported in 1931, in California (1), McWhorter and Lawrence (2) controlled "little-leaf" on deciduous fruit trees near The Dalles by zinc treatments initiated in 1933. Economic results from use of zinc with cane fruits were obtained on Powell silt loam from 1939 (5, 6, 7). The soil types in Oregon that are now known to respond to zinc include approximately 100,000 acres in eight counties.

## MATERIALS AND METHODS

Laboratory greenhouse and field plot studies with zinc have included a dozen soil types and several indicator plants. In the greenhouse trials corn, Bountiful beans, and tomatoes have been most commonly used. Four kinds of cane fruits have been included in major field trials. In the greenhouse six replications, and in the field two or three replications have been used. Following exploratory trials with various soils, major attention was centered on Powell silt loam Newberg sandy loam, Chehalis silty clay loam, Olympic silty clay loam, and Amity silty clay loam. Zinc determinations were made by the dithizone method (4, p. 359) and with the use of a Coleman spectrophotometer. The field plots were $\frac{1}{10}$ acre or more in size.

## EXPERIMENTAL RESULTS

### Zinc in Oregon soils

Only limited amounts of available zinc occur in Powell silt loam, Newberg sandy loam, or certain Oregon peats. Zinc tends to accumulate with organic matter in the surface soil. Availability is lower in soils of basic reaction than in acid or neutral soils. Some 5 per cent of the total zinc in Powell silt loam is

in water-soluble form, whereas 20 to 100 per cent of the zinc applied is exchangeable. these are taken as available forms and are as shown in tables 1 and 2.

TABLE 1

*Water-soluble, replaceable, and total zinc content of dry Newberg loamy sand*

| TREATMENT* | WATER-SOLUBLE Zn | REPLACEABLE Zn | TOTAL† Zn | CALCULATED TOTAL Zn |
|---|---|---|---|---|
| | γ/gm. | γ/gm. | γ/gm. | γ/gm. |
| Ck. | 0.0 | 3.6 | 50 | 50 |
| N−P−K. | 0.0 | ... | 50 | 50 |
| N−P−K+Zn 20 p.p.m. | 0.0 | 5 | 60 | 70 |
| N−P−K+Zn 40 p.p.m. | 0.0 | 6 | 50 | 90 |
| N−P−K+Zn 80 p.p.m. | 0.0 | 8 | 40 | 130 |
| N−P−K+Zn 100 p.p.m. | 0.0 | 8 | 70 | 150 |
| N−P−K+Zn 160 p.p.m. | .3 | 10 | 190 | 210 |

    * Treated February 10, 1941, sampled August 29, 1941.  Zn treatment in form of chloride·
    † These pots have a drain-hole at bottom, and some zinc might have been leached out·

TABLE 2

*Water-soluble, repleaceable, and total zinc content of Powell silt loam*

| TREATMENT* | WATER-SOLUBLE Zn | | REPLACEABLE Zn | | TOTAL Zn | | CALCULATED TOTAL Zn |
|---|---|---|---|---|---|---|---|
| | Top Soil | Bottom Soil | Top Soil | Bottom Soil | Top Soil | Bottom Soil | |
| | γ/gm. | γ/gm. | γ/gm. | γ/gm. | γ/gm. | γ/gm. | γ/gm. |
| Ck. | 0.0 | 0.0 | 6 | 4 | 100 | 90 | 100 |
| N−P−K. | 0.0 | 0.0 | 2 | 3 | 140 | 120 | 100† |
| ..... Zn 20 p.p.m. | 0.0 | 0.0 | 8 | 6 | 150 | 140 | 120 |
| N−P−K+Zn 10 p.p.m. | 0.0 | 0.0 | 12 | 8 | 120 | 110 | 110 |
| N−P−K+Zn 20 p.p.m. | 0.0 | 0.0 | 16 | 12 | 160 | 140 | 130 |
| N−P−K+Zn 20 p.p.m. | 0.4 | 0.4 | 9 | 4 | 110 | 140 | 120 |
| N−P−K+Zn 40 p.p.m. | 0.0 | 0.0 | 32 | 24 | 170 | 170 | 140 |
| N−P−K+Zn 80 p.p.m. | 1.2 | 0.8 | 90 | 70 | 150 | 180 | 180 |
| N−P−K+Zn 120 p.p.m. | 1.5 | 2.0 | 130 | 120 | 250 | 210 | 220 |
| N−P−K+Zn 240 p.p.m. | 4.0 | 5.0 | 200 | 180 | 280 | 300 | 340 |
| N−P−K+Zn 480 p.p.m. | 5.0 | 6.0 | 280 | 240 | 350 | 400 | 580 |

    * Treated October 15, 1940, sampled March 28, 1941, after Bountiful bean crop.  Zn treatment in form of chloride.
    † Impurity.

### Zinc distribution in plant parts

Zinc is found to accumulate in plant roots, stems, and leaves more than it does in the fruit or seed (fig. 1, tables 3 and 4).  The zinc content of leaves of stone fruits is low where little-leaf occurs.  The first few fruits or seeds are richer in zinc than the later pickings.  The tomato is a good indicator plant for zinc trials, whereas the zinc content of oats or beans is relatively low (fig. 2).
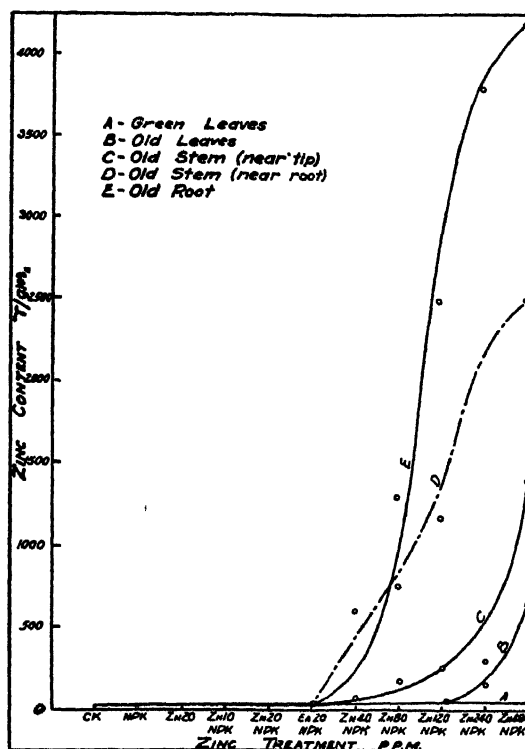
FIG. 1. VARIATION IN ZINC CONTENTS OF DIFFERENT PARTS OF PLANTS GROWN ON POWELL SILT LOAN UNDER DIFFERENT ZINC TREATMENTS

### Economic value of zinc

In field plot trials on Powell silt loam, 30 pounds of zinc sulfate an acre applied every second year produced a 4-year average increase of 0.46 ton an acre and a net profit over the cost of the treatment of $110.33 with red raspberries and

TABLE 3

*Zinc content of field corn plant parts on Newberg loamy sand plots*

| TREATMENT* | Zn IN LEAF | | Zn IN STEM | | Zn IN ROOT | | Zn IN OLD KERNEL |
|---|---|---|---|---|---|---|---|
| | Young | Old | Young | Old | Young | Old | |
| | $\gamma/gm.$ | $\gamma/gm.$ | $\gamma/gm.$ | $\gamma/gm.$ | $\gamma/gm.$ | $\gamma/gm.$ | $\gamma/gm.$ |
| Ck................................. | 10 | 52 | 30 | 28 | 30 | 20 | 20 |
| N−P−K+Zn 20 p.p.m.............. | 66 | 20 | 180 | 50 | 90 | 25 | 60 |
| N−P−K+Zn 20 p.p.m............. | 45 | 30 | 40 | 50 | 25 | 50 | 35 |
| N−P−K+Zn 40 p.p.m............. | 10 | 30 | 25 | 10 | 40 | 35 | 55 |
| N−P−K+Zn 40 p.p.m............. | 2 | 45 | 5 | 25 | 4 | 35 | 40 |
| N−P−K+Zn 80 p.p.m............. | 60 | 160 | 10 | 40 | 45 | 60 | 65 |
| N−P−K+Zn 160 p.p.m............ | 90 | 100 | 35 | 22 | 50 | 25 | 5 |

* Treated May 1. Zn treatment in form of chloride. Tests for young leaves, stems, and roots made on plants 5 weeks after thinning.

TABLE 4

## TABLE 4

*Yield and zinc content of sunflowers grown on Powell silt loam*

| TREATMENT PER ACRE | | AIR-DRY WEIGHT | | | ZINC CONTENT | | |
|---|---|---|---|---|---|---|---|
| | | Flowers | Leaves | Stems | Flowers | Leaves | Stems |
| | lbs. | gm. | gm. | gm. | mgm./kgm. | mgm./kgm. | mgm./kgm. |
| None.......................... | | 5.5 | 15.5 | 29.0 | 149 | 166 | 150 |
| Zinc chloride................... | 40 | 7.0 | 11.0 | 26.0 | 166 | 428 | 230 |
| Zinc sulfate................... | 40 | 6.0 | 15.0 | 29.5 | 234 | 452 | 372 |
| Zinc powder................... | | 6.0 | 15.0 | 29.0 | 128 | 270 | 242 |
| Zinc acetate................... | 40 | 5.5 | 16.0 | 30.5 | 132 | 312 | 214 |
| Zinc carbonate................ | 40 | 5.5 | 15.0 | 27.0 | 260 | 666 | 486 |
| Zinc nitrate................... | 40 | 2.0 | 15.5 | 28.5 | 170 | 444 | 340 |
| N−P−K check................ | | 5.0 | 14.5 | 25.5 | 36 | 64 | 68 |
| Zinc chloride................... | 10 | 6.0 | 13.5 | 25.0 | 90 | 184 | 150 |
| Zinc chloride................... | 20 | 5.0 | 17.0 | 28.0 | 226 | 396 | 320 |
| Zinc chloride................... | 40 | 5.0 | 18.0 | 30.0 | 50 | 182 | 120 |
| Zinc chloride................... | 80 | 7.0 | 17.0 | 31.0 | 98 | 352 | 308 |
| Zinc chloride................... | 160 | 3.0 | 7.0 | 13.0 | 124 | 564 | 552 |
| Zinc chloride................... | 320 | 1.5 | 6.0 | 7.0 | 216 | 810 | 952 |
| N−P−K check............... | | 3.5 | 8.0 | 14.5 | 22 | 14 | 16 |
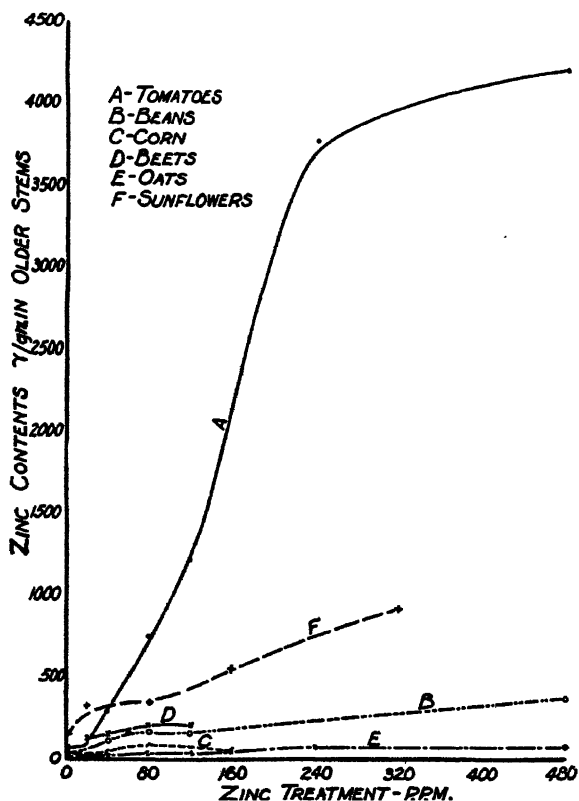


FIG. 2. ZINC CONTENTS OF STEMS OF DIFFERENT PLANTS AS AFFECTED BY ZINC TREATMENT

0.15 ton gain or a net increase of $29.33 with Boysenberries (6). On Amity silty clay loam this zinc treatment gave 0.47 ton increase in the gooseberry yield and increased the net profit $76 an acre.

In The Dalles orchard district, zinc sprays have corrected little-leaf on apricots, cherries, peaches, prunes, pears, and apples. Little-leaf is found to a lesser extent in Umatilla, Union, and Jackson Counties. The lighter textured soils of the Deschutes series have given response to zinc in greenhouse trials.

### Rate and method of application

Zinc in various forms and amounts was applied to Powell silt loam. The effect on beans is shown in table 5.

TABLE 5

*Yield and zinc content of Bountiful bean plants\* grown on Powell silt loam*

| TREATMENT PER ACRE | YIELD OF 28 PLANTS | | ZINC† |
|---|---|---|---|
| | Number of pods | Weight | |
| | | *gm.* | *mgm./kgm.* |
| Check.................... ........ | 29 | 17.1 | 28 |
| ZnCl₂ 40 lbs................ .. | 35 | 22.5 | 29 |
| ZnSO₄ 40 lbs.................... | 38 | 30.0 | 217 |
| Zn powder 40 lbs............... | 28 | 16.8 | 178 |
| Zn acetate 40 lbs............... | 29 | 17.9 | 276 |
| Zn carbonate 40 lbs............ | 32 | 20.6 | 317 |
| Zn (NO₃)₂ 40 lbs............. . | 33 | 21.8 | 117 |
| NPK check.................... | 42 | 15.9 | 80 |
| ZnCl₂ 10 lbs................... | 25 | 17.9 | 120 |
| ZnCl₂ 20 lbs.................. | 33 | 17.4 | 122 |
| ZnCl₂ 40 lbs.................. | 32 | 22.3 | 135 |
| ZnCl₂ 80 lbs.................. | 27 | 16.6 | 187 |
| ZnCl₂ 160 lbs................. | 29 | 25.1 | 301 |
| ZnCl₂ 320 lbs................ . | 30 | 14.1 | 536 |
| NPK check................. | 112 | 16.8 | 26 |

\* Analysis of whole plant, dry basis, average of four cultures.
† Determinations by G. J. Joaquera.

Though zinc chloride has been included in experimental trials to avoid the sulfur effect, it is caustic and requires careful handling. Zinc sulfate is a readily available and practical form in which to supply this element. Forty to eighty pounds an acre is found to be a suitable rate of application (fig. 3) on moderately acid soils, say pH 5.5 to 6.5. Use of 320 pounds an acre has proved to be toxic to sunflowers and gooseberries. A relationship between zinc and phosphate absorption has been observed in these studies.

In the orchards near The Dalles, zinc sulfate injections and specially placed zinc tacks or nails are reported by McWhorter (3) to be slowly effective but to correct little-leaf for some 3 years. The foliar spray needs to be applied two or three times in the season. The dormant spray applied just before the buds swell and open has given outstanding results and is now favored there. Fifty pounds

FIG. 3. GROWTH RESPONSE OF TOMATO PLANTS AS AFFECTED BY
DIFFERENT ZINC TREATMENTS

Zn in parts per million added to NPK as indicated
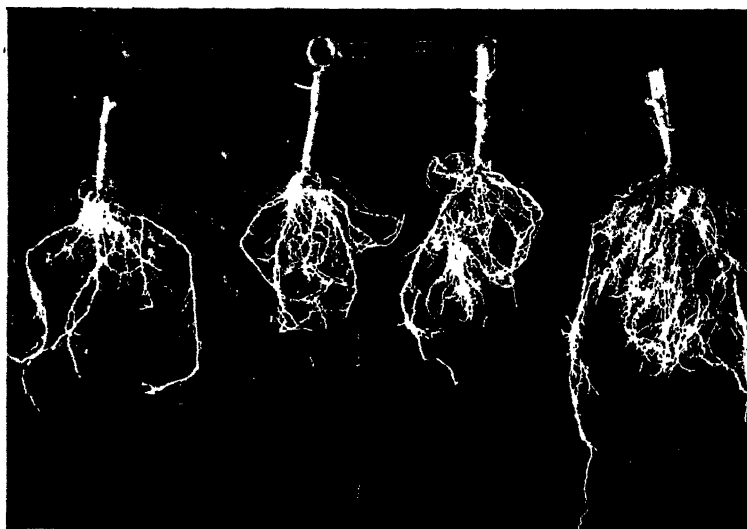


FIG. 4. EFFECT OF ZINC ON TOMATO ROOT DEVELOPMENT
FROM LEFT CHECK, ZN $60_1$, $NPK_1$, ZN 60 + NPK

Left to right: check, Zn 60 p.p.m., NPK, Zn 60 p.p.m. + NPK

of zinc sulfate is used with 100 gallons of water. For the foliar spray the use
of 18 pounds zinc sulfate per 100 gallons water and 6 pounds of well-slacked lime
is suggested to avoid possible burning of foliage especially where 6 pounds of
borax is added to the spray mixture (4). Spraying early or late in the day is

also advised. In recent replicated greenhouse tests, use of zinc sulfate with sulfur and manure gave maximum yields.

### Effects

Zinc in these studies has increased weight and length of roots (fig. 4), and its absorption appears to be related to phosphorus (table 6). Seed treatments that included zinc hastened and improved germination of *Lotus corniculatus* in tests. Of 1,200 untreated seeds, 21 per cent germinated in 8 days. A like number treated with 1 per cent zinc oxide showed 67 per cent germination, and on the eighth day 24 per cent more germination. Zinc has hastened blooming, controlled little-leaf, and increased yields (6).

### TABLE 6
*Zinc content of corn grown on Powell silt loam with different zinc treatments*

| TREATMENT | LEAF | | STEM | | ROOT | | ROOT (1 GALLON) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 gallon jar | 2 gallons | 1 gallon | 2 gallons | 1 gallon | 2 gallons | weight | length | Zn in 1 root |
| | γ/gm. | γ/gm. | γ/gm. | γ/gm. | | | gm. | cm. | γ |
| Ck................................. | 25 | 20 | 5 | 22 | 25 | 15 | 0.9 | 4.0 | 32 |
| N−P−K............................. | 50 | 20 | 4 | 15 | 64 | 80 | 2.8 | 5.5 | 196 |
| .....−Zn 100 p.p.m...................... | 75 | 55 | 35 | 7 | 190 | 25 | 1.3 | 5.8 | 165 |
| ........−P 100 p.p.m.................. | 50 | 85 | 18 | 5 | 175 | 100 | 1.8 | 4.5 | 275 |
| N−K+Zn 100 p.p.m., P 100 p.p.m....... | 35 | 135 | 35[20] | 25 | 187− | 50 | 1.9 | 5.0 | 523 |
| N−K+Zn 100 p.p.m., P 200 p.p.m....... | 40 | 60 | 10 | 15 | 50 | 110 | 7.4 | 15.0 | 370 |
| N−K+Zn 100 p.p.m., P 300 p.p.m....... | 45 | 65 | 70 | 80 | 375 | 130 | 5.5 | 12.8 | 1,925 |

### SUMMARY AND CONCLUSIONS

The several soil series in Oregon that have thus far been found to be low in available zinc include approximately 100,000 acres. Zinc additions increase the available and particularly the exchangeable zinc and restore normal growth. Zinc has been found to overcome little-leaf, quicken germination, aid root development, hasten pollination, and advance the time of maturity. Pelleted seed treatments including zinc salts have resulted in hastened and increased germination of *Lotus corniculatus*. Significant crop response has been obtained from use of zinc on Powell silt loam in the planthouse and field with broccoli, beans, tomatoes, corn, sunflowers, and cane fruit.

Analyses of plant parts show that the order of zinc accumulation in plants is: roots > stems > leaves > fruits.

Zinc sulfate is a readily available and practical form in which to supply this element. Forty to eighty pounds an acre is a suitable rate of application here. Furrow application with acidified organic matter has given the most enduring results on faintly acid soil of the humid region. For deciduous fruits on basic soils a dormant spray of 50 pounds of zinc sulfate per 100 gallons of water before buds open is favored.

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# INCREASES IN NITROGEN FROM GROWING ALFALFA
## ON DRY LAND

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Maintaining the nitrogen supply of soil at a productive crop level is one of the major problems of western dry-land agriculture. The low amount of nitrogen in virgin soils together with the soil-depleting characteristics of the cropping practice of alternate wheat and fallow can make nitrogen rather than moisture the limiting factor of crop production. In certain dry-land areas the nitrogen in the soil has been maintained by growing alfalfa for an indefinite period followed by a few years of wheat and then when yield and quality of grain fall to lower levels returning the land to alfalfa again. The investigation reported here was started for the purpose of measuring changes in nitrogen content of soil planted to alfalfa for varying numbers of years following wheat.

### EXPERIMENTAL METHODS

In selecting land for this study, it was necessary to find fields of alfalfa and wheat adjacent but separated by a strip of unplowed virgin land. Such areas as railroad right-of-ways, old roads, and wide untilled fence lines all in grass were selected as the virgin land. According to local records and appearances, none of the areas selected to represent virgin conditions had ever been plowed or cropped. All combinations of cropped and virgin fields were carefully selected according to topography, soil conditions, and land use so that any complete sampling site would have been as near uniform as possible in the initial virgin state and so that the cultivated fields would have been modified as little as possible by erosion or factors other than cropping and tillage practices. Twenty such combinations were found in Cache Valley in northern Utah and two in Juab Valley in central Utah. The farms selected in Cache Valley had been cropped for 40 to 50 years; in Juab Valley land in wheat had been cropped for 35 years, but alfalfa had been seeded on virgin land 10 years previous.

In collecting soil for analysis, five samples were taken to a depth of 3 feet and composited in 1-foot sections at each of five locations on alfalfa, wheat, and virgin land. At each location paired composite samples were taken from immediately adjacent alfalfa, wheat, and virgin areas. Total nitrogen was determined by the Kjeldahl method.

Cache Valley soils, laid down in prehistoric Lake Bonneville, have since been worked over by surface agencies. Soils of the fields sampled varied in texture from silt loams to clay loams. Juab Valley soils, weathered from adjacent mountain ranges, are classified as clay loams. Average annual rainfall in Cache Valley varies from 16 to 17 inches, and in Juab Valley from 12 to 14 inches.

[1] Professor of agronomy and graduate student, respectively.

The cropping system followed on the farms in Cache Valley included in this study consisted of growing alfalfa on wheat land for indefinite periods. At the time samples were collected, alfalfa ranged in age from 2 to 30 years. On

TABLE 1

*Comparison of nitrogen percentages in the first foot of virgin and of dry-farm alfalfa and wheat land on 20 farms in Cache Valley, Utah*

| FARM | PERIOD IN ALFALFA AFTER WHEAT | NITROGEN IN SOILS | | | GAIN OF ALFALFA OVER WHEAT | LOSS OF WHEAT FROM VIRGIN | LOSS OF ALFALFA FROM VIRGIN | RECOVERY OF ALFALFA OVER WHEAT* |
|---|---|---|---|---|---|---|---|---|
| | | Virgin | Alfalfa | Wheat | | | | |
| | *years* | *per cent* | *per cent* | *per cent* | *per cent of wheat* | *per cent of virgin* | *per cent of virgin* | *per cent* |
| McQueen............ | 30 | .142 | .137 | .127 | 7.9 | 10.6 | 3.5 | 66.7 |
| McQueen............ | 22 | .148 | .142 | .119 | 19.3 | 19.6 | 4.0 | 79.3 |
| Swan................ | 20 | .136 | .131 | .119 | 11.0 | 12.5 | 3.7 | 70.6 |
| Condie.............. | 19 | .155 | .138 | .121 | 14.0 | 21.9 | 11.0 | 50.0 |
| Wheeler............. | 15 | .143 | .131 | .118 | 11.1 | 17.5 | 8.4 | 52.0 |
| Group means....... | 21.2 | .145 | .136 | .121 | 12.4† | 16.5† | 6.2† | 62.5† |
| Larson.............. | 13 | .153 | .151 | .135 | 11.8 | 11.8 | 1.3 | 88.9 |
| Clawson............ | 12 | .135 | .132 | .117 | 12.8 | 13.3 | 2.2 | 83.3 |
| Kidman............. | 12 | .264 | .254 | .200 | 27.0 | 24.2 | 3.8 | 84.4 |
| Warner............. | 10 | .207 | .202 | .174 | 16.1 | 15.9 | 2.4 | 84.8 |
| C. Butters.......... | 10 | .249 | .202 | .182 | 11.0 | 26.9 | 18.9 | 30.0 |
| Scott-Butters....... | 10 | .169 | .159 | .143 | 11.1 | 15.4 | 5.9 | 61.5 |
| Peterson............ | 10 | .236 | .207 | .183 | 13.1 | 22.4 | 12.3 | 45.3 |
| Group means...... | 10.7 | .202 | .187 | .162 | 15.4† | 19.8† | 7.4† | 62.5† |
| Condie.............. | 5 | .163 | .131 | .117 | 11.9 | 28.2 | 19.6 | 30.4 |
| Stokes.............. | 4 | .128 | .124 | .111 | 11.7 | 13.3 | 3.1 | 76.5 |
| Wheeler............ | 4 | .143 | .132 | .117 | 12.8 | 18.2 | 7.7 | 57.7 |
| Condie.............. | 4 | .120 | .113 | .103 | 9.7 | 14.2 | 5.8 | 58.8 |
| R. Butters.......... | 4 | .152 | .126 | .111 | 13.5 | 27.0 | 17.1 | 36.6 |
| Anderson-Christiansen............ | 3 | .238 | .205 | .180 | 14.0 | 24.4 | 13.7 | 43.1 |
| R. Butters.......... | 3 | .210 | .164 | .146 | 12.3 | 30.5 | 21.9 | 28.1 |
| Condie.............. | 2 | .152 | .119 | .111 | 7.2 | 27.0 | 21.7 | 19.5 |
| Group means...... | 3.625 | .163 | .139 | .124 | 12.1† | 23.9† | 14.7† | 38.5† |
| Grand means...... | | .172 | .155 | .137 | 13.1† | 20.3† | 9.9† | 51.4† |

\* See text footnote 3.

† Calculated from nitrogen percentages.

adjacent land in grain, cropping consisted in alternating wheat with fallow. In Juab Valley, alfalfa, which was 10 years old when soil samples were taken, had been planted on virgin land. Wheat was alternated with fallow.

## RESULTS AND DISCUSSION

Data showing comparisons of nitrogen content for virgin, alfalfa, and wheat land are given in tables 1 to 5. Each percentage of nitrogen given in these

TABLE 2

*Comparison of nitrogen percentages in the second foot of virgin and of dry-farm wheat and alfalfa land on 20 farms in Cache Valley, Utah*

| FARM | PERIOD IN ALFALFA AFTER WHEAT | NITROGEN IN SOIL | | | GAIN OF ALFALFA OVER WHEAT | LOSS OF WHEAT FROM VIRGIN | LOSS OF ALFALFA FROM VIRGIN | RECOVERY OF ALFALFA OVER WHEAT |
|---|---|---|---|---|---|---|---|---|
| | | Virgin | Alfalfa | Wheat | | | | |
| | years | per cent | per cent | per cent | per cent of wheat | per cent of virgin | per cent of virgin | per cent |
| McQueen | 30 | .094 | .093 | .088 | 5.7 | 6.4 | 1.0 | 83.3 |
| McQueen | 22 | .085 | .082 | .074 | 10.8 | 12.9 | 3.5 | 72.7 |
| Swan | 20 | .101 | .088 | .083 | 6.0 | 17.8 | 12.9 | 27.8 |
| Condie | 19 | .087 | .076 | .070 | 8.6 | 19.5 | 12.6 | 35.3 |
| Wheeler | 15 | .118 | .091 | .082 | 11.0 | 30.5 | 22.9 | 25.0 |
| Group means | | .097 | .086 | .079 | 8.9* | 18.5* | 11.3* | 38.9* |
| Larson | 13 | .111 | .108 | .102 | 5.9 | 8.1 | +2.7 | 66.7 |
| Clawson | 12 | .074 | .075 | .066 | 13.6 | 10.8 | 1.3 | 112.5 |
| Kidman | 10 | .158 | .131 | .130 | 0.8 | 17.7 | 17.1 | 3.6 |
| Warner | 10 | .145 | .144 | .133 | 8.3 | 8.3 | 0.7 | 91.7 |
| C. Butters | 10 | .197 | .158 | .142 | 11.3 | 27.9 | 19.8 | 29.1 |
| Scott-Butters | 10 | .144 | .121 | .106 | 14.1 | 26.4 | 16.0 | 39.5 |
| Peterson | 10 | .196 | .161 | .153 | 5.2 | 21.9 | 17.8 | 18.6 |
| Group means | | .146 | .128 | .119 | 7.6* | 18.5* | 12.3* | 33.3* |
| Condie | 5 | .089 | .091 | .071 | 28.2 | 20.2 | +2.2 | 111.1 |
| Stokes | 4 | .083 | .073 | .072 | 1.4 | 13.2 | 12.0 | 9.1 |
| Wheeler | 4 | .087 | .079 | .064 | 23.4 | 26.4 | 9.2 | 65.2 |
| Condie | 4 | .078 | .069 | .057 | 21.0 | 26.9 | 11.5 | 57.1 |
| R Butters | 4 | .086 | .068 | .067 | 1.5 | 22.1 | 18.6 | 5.3 |
| Anderson-Christiansen | 3 | .188 | .173 | .154 | 12.3 | 18.1 | 8.0 | 55.9 |
| R. Butters | 3 | .145 | .112 | .101 | 10.9 | 30.3 | 22.7 | 25.0 |
| Condie | 2 | .105 | .084 | .072 | 16.7 | 31.4 | 20.0 | 36.4 |
| Group means | | .108 | .094 | .082 | 14.6* | 24.1* | 12.9* | 46.1* |
| Grand means | | .118 | .104 | .094 | 11.1* | 20.3* | 11.9* | 41.7* |

\* Calculated from nitrogen percentages.

tables is an average of five composite samples. Results for the first foot are shown in table 1. The 20 farms are divided into three age groups on the basis of time alfalfa had been grown following wheat. The first period ranged from 15 to 30 years, the second from 10 to 13 years, and the last from 2 to 5 years.

The five farms in the first group were 16.5 per cent lower in nitrogen than adjacent virgin areas, in the second group 19.8 per cent lower, and 23.9 per cent lower in the last group, with an average difference of 20.3 per cent for all 20 farms. There was no significant difference among the three group means, but differences

TABLE 3

*Comparison of nitrogen percentages in the third foot of virgin and of dry-farm alfalfa and wheat land on 20 farms in Cache Valley, Utah*

| FARM | PERIOD IN ALFALFA AFTER WHEAT | NITROGEN IN SOIL | | | GAIN OF ALFALFA OVER WHEAT | LOSS OF WHEAT FROM VIRGIN | LOSS OF ALFALFA FROM VIRGIN | RECOVERY OF ALFALFA OVER WHEAT |
|---|---|---|---|---|---|---|---|---|
| | | Virgin | Alfalfa | Wheat | | | | |
| | *years* | *per cent* | *per cent* | *per cent* | *per cent of wheat* | *per cent of virgin* | *per cent of virgin* | *per cent* |
| McQueen............ | 30 | .085 | .082 | .094 | −12.8 | +9.6 | 3.5 | |
| McQueen............ | 22 | .061 | .060 | .056 | 7.1 | 8.2 | 1.6 | 80.0 |
| Swan............... | 20 | .066 | .063 | .065 | −3.1 | 1.5 | 4.5 | −200.0 |
| Condie............. | 19 | .046 | .040 | .038 | 5.3 | 17.4 | 13.0 | 25.0 |
| Wheeler............ | 15 | .057 | .055 | .050 | 10.0 | 12.3 | 3.5 | 71.4 |
| Group means..... | | .063 | .060 | .060 | 0* | 4.8* | 4.8* | 0* |
| Larson.............. | 13 | .082 | .069 | .080 | −15.9 | 2.4 | 15.8 | −550.0 |
| Clawson............ | 12 | .056 | .054 | .056 | −3.6 | 0 | 3.6 | 0 |
| Kidman............ | 12 | .092 | .084 | .086 | −2.3 | 6.5 | 8.7 | −33.3 |
| Warner............. | 10 | .109 | .114 | .100 | 14.0 | 8.2 | +4.6 | 155.5 |
| C. Butters.......... | 10 | .101 | .090 | .081 | 11.1 | 19.8 | 10.9 | 45.0 |
| Scott-Butters....... | 10 | .101 | .086 | .080 | 7.5 | 20.8 | 14.8 | 28.6 |
| Peterson............ | 10 | .109 | .072 | .072 | 0 | 33.9 | 33.9 | 0 |
| Group means..... | | .093 | .081 | .079 | 2.5* | 15.9* | 13.8* | 14.3* |
| Condie............. | 5 | .066 | .062 | .048 | 29.2 | 27.3 | 6.1 | 77.8 |
| Stokes............. | 4 | .061 | .057 | .054 | 5.5 | 11.5 | 6.6 | 42.8 |
| Wheeler............ | 4 | .069 | .050 | .057 | −12.3 | 17.4 | 27.5 | −58.3 |
| Condie............. | 4 | .046 | .032 | .038 | −15.8 | 17.4 | 30.4 | −75.0 |
| Butters............. | 4 | .041 | .038 | .035 | 8.6 | 14.6 | 7.3 | 50.0 |
| Anderson-Christiansen........... | 3 | .114 | .099 | .093 | 6.4 | 18.4 | 13.1 | 28.6 |
| R. Butters......... | 3 | .090 | .063 | .066 | −4.5 | 26.7 | 30.0 | −12.5 |
| Condie............. | 2 | .067 | .056 | .053 | 5.7 | 20.9 | 16.4 | 21.4 |
| Group means..... | | .069 | .057 | .055 | 3.6* | 20.3* | 17.4* | 14.3* |
| Grand means..... | | .076 | .066 | .065 | 1.5* | 14.5* | 13.2* | 9.1* |

between virgin and wheat land were highly significant in favor of virgin land. In a previous study[2] of nitrogen losses, virgin land was found to be 15.9 per cent

[2] BRACKEN, A. F., AND GREAVES, J. E. Losses of nitrogen and organic matter from dry farm soils. *Soil Sci.*, 51: 1–15. 1941.

higher in nitrogen in Cache Valley and 14.5 per cent higher in Juab Valley than wheat land. In gain in nitrogen of land planted to alfalfa over adjacent wheat land, the mean for the twenty farms was 13.1 per cent with no significant dif-

TABLE 4

*Increase of nitrogen in soil from growing alfalfa for various numbers of years, amount of nitrogen removed by hay, total pounds of nitrogen increase, and total nitrogen increase per acre per year for 20 farms in Cache Valley, Utah*

| FARM | PERIOD IN ALFALFA FOLLOWING WHEAT | 1 TOTAL N INCREASE PER ACRE FROM ALFALFA SOILS AND HAY | 2 TOTAL N REMOVED IN HAY PER ACRE | 3 TOTAL N INCREASE IN SOIL PER ACRE | 4 TOTAL N INCREASE PER ACRE PER YEAR |
|---|---|---|---|---|---|
| | years | lbs. | lbs. | lbs. | lbs. |
| McQueen............... | 30 | 2268 | 2160 | 108 | 76 |
| McQueen............... | 22 | 2844 | 1584 | 1260 | 129 |
| Swan.................. | 20 | 1980 | 1440 | 540 | 99 |
| Condie................ | 19 | 2268 | 1368 | 900 | 119 |
| Wheeler............... | 15 | 2052 | 1080 | 972 | 137 |
| Group means......... | | 2318 | 1526 | 792* | 112 |
| Larson................ | 13 | 1332 | 936 | 396 | 102 |
| Clawson............... | 12 | 1656 | 864 | 792 | 138 |
| Kidman............... | 10 | 2628 | 720 | 1908 | 263 |
| Warner................ | 10 | 2628 | 720 | 1908 | 263 |
| C. Butters............ | 10 | 2340 | 720 | 1620 | 234 |
| Scott-Butters......... | 10 | 2052 | 720 | 1332 | 205 |
| Peterson.............. | 10 | 1872 | 720 | 1152 | 187 |
| Group means......... | | 2067 | 771 | 1296* | 199 |
| Condie................ | 5 | 2088 | 360 | 1728 | 418 |
| Stokes................ | 4 | 900 | 288 | 612 | 225 |
| Wheeler............... | 4 | 1116 | 288 | 828 | 279 |
| Condie................ | 4 | 864 | 288 | 576 | 216 |
| R. Butters............ | 4 | 972 | 288 | 684 | 243 |
| Anderson-Christiansen.............. | 3 | 2016 | 216 | 1800 | 672 |
| R Butters............. | 3 | 1252 | 216 | 936 | 424 |
| Condie................ | 2 | 972 | 144 | 828 | 486 |
| Group means......... | | 1305 | 261 | 1044* | 370 |
| Grand means......... | | 1804 | 760 | 1044* | 246 |

\* Calculated from nitrogen percentage means.

ference among the three age group means. In no case did the percentage of nitrogen in alfalfa land equal that found in virgin land. On an average, the virgin land contained 9.9 per cent more nitrogen than the alfalfa land.

Recovery[3] of nitrogen in alfalfa land varied from 19.5 per cent for the Condie farm, where alfalfa was grown for 2 years, to 88.9 per cent for the Larson land, which had been in alfalfa 13 years. The means showed 62.5 per cent recovery for the first two groups and 38.5 per cent for the 2- to 5-year period. The difference between the three age groups is not significant when all figures are considered. If the C. Butters farm, which showed a 30 per cent recovery, is omitted from the second group, and the Stokes farm, with a difference of 76.5 per cent, from the third, however, the first two group means become significantly different from the last.

Data in table 2 show percentages of nitrogen in the second foot. Again none of the age group means are statistically different. Nitrogen in wheat land was found to be 20.3 per cent lower than in adjacent virgin land, a figure identical with the difference between these groups for the first foot. Land in alfalfa was

TABLE 5

*Comparison of nitrogen percentages for virgin and for dry-farm alfalfa and wheat land on two farms in Juab Valley, Utah*

| FARM | DEPTH | NITROGEN IN SOIL | | | GAIN OF ALFALFA OVER WHEAT | LOSS OF WHEAT FROM VIRGIN | LOSS OF ALFALFA FROM VIRGIN | RECOV-ERY OF ALFALFA OVER WHEAT |
|---|---|---|---|---|---|---|---|---|
| | | Virgin | Alfalfa | Wheat | | | | |
| | *feet* | *per cent* | *per cent* | *per cent* | *per cent of wheat* | *per cent of virgin* | *per cent of virgin* | *per cent* |
| Serle-Fowkes | 1 | .131 | .126 | .104 | 21.1 | 20.6 | 3.8 | 81.5 |
| | 2 | .075 | .073 | .069 | 5.8 | 8.0 | 2.7 | 66.7 |
| | 3 | .051 | .051 | .048 | 6.2 | 5.9 | 0 | 100.0 |
| Tophin-Byland | 1 | .148 | .150 | .134 | 11.9 | 9.4 | 1.3 | 114.3 |
| | 2 | .098 | .096 | .088 | 9.1 | 10.2 | 2.0 | 80.0 |
| | 3 | .079 | .080 | .078 | 2.6 | 2.3 | 1.3 | 200.0 |
| Means | | .098 | .096 | .087 | 10.3 | 11.2 | 2.0 | 81.8 |

11.1 per cent higher in nitrogen than wheat land, and virgin areas were 11.9 per cent higher in nitrogen than adjacent land growing alfalfa. All three means show high statistical difference. Comparison of amounts of nitrogen in virgin and alfalfa land, in the second foot, shows that the differences are not so consistent as those for the first foot. In two instances, alfalfa land was higher in nitrogen than adjacent virgin land. The mean difference of 11.9 per cent in favor of virgin land as compared to land in alfalfa for the 20 farms is highly significant.

Recovery of nitrogen by growing alfalfa indicated wide variation in the second foot. On the Clawson and Condie (5 years) farms, soil samples from alfalfa

[3] Recovery of nitrogen from growing alfalfa following wheat is based on the difference in nitrogen content between alfalfa and wheat land as shown by soil samples according to the formula $\dfrac{\text{(alfalfa} - \text{wheat)}}{\text{(virgin} - \text{wheat)}} \cdot 100$.

lands were found to contain more nitrogen than samples from adjacent virgin lands. These results gave nitrogen recovery estimates from growing alfalfa of 112.5 and 111.1 per cent, respectively. The lowest estimated nitrogen recoveries were found on the Kidman and R. Butters lands with 3.6 per cent on the former and 5.3 per cent on the latter. For the 20 farms, recovery averaged 41.7 per cent. In comparing the first- and second-foot recoveries, the difference of 9.7 per cent between the two hardly reached the 5 per cent level of significance. But if the first two groups (10–13 and 15–30 years) in tables 1 and 2 are compared, the difference is significant.

Data on the percentages of nitrogen in the third foot appear in table 3. No significant differences were found among means of the three age groups. Nitrogen in wheat land averaged 14.5 per cent lower and in alfalfa land 13.2 per cent lower than virgin land. Both differences were highly significant. On an average, the third foot of land in alfalfa contained only 1.5 per cent more nitrogen than the third foot of wheat land, and the estimated recovery of nitrogen lost from wheat land through growing alfalfa amounted to 9.1 per cent. The small differences in nitrogen content of cropped and virgin lands gave very erratic results for estimated nitrogen recovery from growing alfalfa, with none of the means significantly different. Thus these data indicate that accumulation of nitrogen from growing alfalfa occurred largely in the first and the second foot.

In addition to soil samples from the 20 farms, samples of the hay were taken from several for nitrogen analysis. Nitrogen content of the hay averaged 2.34 per cent. From county figures, hay yields were estimated at 3,000 pounds to an acre. The figures in table 4 were calculated by using these values and the increase in nitrogen content of the soil to a depth of 3 feet from growing alfalfa after wheat. Column 2 shows the pounds of nitrogen removed in the hay per acre over the period of cropping to alfalfa. In column 3 is shown the average amount of nitrogen per acre in the alfalfa land in excess of that in the wheat land. These values added together give the results in column 1, which when divided by the age of the alfalfa give the figures in column 4, representing the total pounds of nitrogen gain per acre per year. Age-group means for total nitrogen increase per acre from alfalfa (column 1); total nitrogen removed in hay per acre; and yearly nitrogen increase per acre (column 4) all showed high statistical differences. Group means for total nitrogen increase in soil per acre, (column 3), on the other hand, showed no statistical difference. This was expected, since group means for percentage recovery of nitrogen from growing alfalfa following wheat showed no statistical difference without elimination of some of the farms showing greatest variation.

The data in column 3 indicates that total accumulative increase of nitrogen per acre varied from 108 up to 1,908 pounds, with an average of 1,044 for the 20 farms. In a similar study, Swanson and Latshaw[4] in comparing nitrogen content of alfalfa, virgin, and grain land in the semiarid part of Kansas found that alfalfa land contained an average of 1,437 pounds more nitrogen per acre

[4] SWANSON, C. O., AND LATSHAW, W. L. Effects of alfalfa on the fertility elements of the soil in comparison with grain crops. *Soil Sci.* 8: 1–39. 1919.

than adjacent wheat land with county averages varying from 760 to 1,900 pounds.

Variations in the total nitrogen increase per acre per year ranged from 76 to 672 pounds, with four farms above 400 pounds. The averages for all 20 farms amounted to 246 pounds. Collinson, Beattie, and Harland[5], in a 16-year lysimeter study in New York, found that hill-soil grown to alfalfa fixed as much as 260 pounds of nitrogen per acre annually. In the work of Swanson and Latshaw, the total amount of nitrogen fixed by alfalfa corresponded closely to the total shown in table 4, column 4, but amounts removed by crops were not indicated. If hay yields were as high in Kansas as in Utah, it is possible the nitrogen increase per year would have been equally high.

Data for the two farms in Juab Valley are presented in table 5. Results for the first foot of soil show that virgin land contained 20.6 per cent more nitrogen than wheat land on the Serle-Fowkes farm and 9.4 per cent more on the Tophin-Byland farm. The average excess of nitrogen in virgin over wheat land to a depth of 3 feet for both farms amounted to 11.2 per cent. Virgin land contained 3.8 per cent more nitrogen than alfalfa land on the Serle-Fowkes farm, but on the Tophin-Byland farm alfalfa land contained 1.3 per cent more than the virgin. Such differences are well within the range of sampling variation. From the limited data it might appear that these soils were near the nitrogen equilibrium level when producing alfalfa.

The question that arises is whether wheat land that has suffered a loss of nitrogen in this area, can be built up to an equally high level by the planting of alfalfa. From table 1 it will be observed that the nitrogen content of several farms in Cache Valley varied between the range in percentage of these two farms in Juab Valley (0.131 and 0.148), yet in every instance land growing alfalfa was lower than adjacent virgin land. Recovery of nitrogen on the farms selected as a comparison ranged from 52.0 to 88.2 per cent. But on certain soils in semiarid sections, gains of nitrogen equal to or greater than those of adjacent virgin land have occurred. Swanson and Latshaw found, in semiarid sections of Kansas with an average of 0.155 per cent nitrogen in virgin land, that fields in alfalfa contained 30 per cent more nitrogen than grain land and 15.7 per cent more than soils in native sod. No recovery of such magnitude was found in this study. From the data presented, it might be considered that in the dry farms of Cache Valley wheat land planted to alfalfa reaches nitrogen equilibrium after approximately 10 years at a level about 7 per cent below that of adjacent virgin land, or at a point two thirds of the way between wheat and alfalfa land.

## SUMMARY

Nitrogen determinations were made on land planted in alfalfa and in wheat and on adjacent virgin soil on 20 farms in Cache Valley, northern Utah, and on two farms in Juab Valley, central Utah. In the Cache Valley area, alfalfa

[5] COLLINSON, R. C., BEATTIE, H. G., AND HARLAND, J. D. Mineral and water relations and final nitrogen balance in legume and non-legume crop rotations for a period of 16 years. N. Y. Agr. Exp. Sta. Tech. Bul. 212. 1933.

varied in age from 2 to 30 years. Fields which had been in alfalfa 10 to 13 years showed as much recovery of nitrogen in the first foot of soil as those that had been in alfalfa 15 to 30 years. Recovery of nitrogen on farms in these two age groups each averaged 62.5 per cent. For the 2- to 5-year age group, recovery amounted to 35.5 per cent. The average loss of nitrogen from growing wheat (comparing virgin with wheat land) was 20.3 per cent. In the second foot of soil, the average loss for the 20 farms studied was also 20.3 per cent and the recovery of this loss of nitrogen by growing alfalfa averaged 41.7 per cent. In the third foot a loss of 14.5 per cent occurred and the recovery by growing alfalfa amounted to 9.1 per cent but was not significant.

Accounting for the nitrogen in the hay, adding this to that accumulated in the soil, and dividing by the years of cropping gave the average yearly increase of nitrogen per acre of 246 pounds. For the 20 farms studied in Cache Valley, the range varied from 76 to 672 pounds.

In Juab Valley, the nitrogen content of the first foot of virgin soil of the two farms sampled was 0.131 and 0.148 per cent, respectively. Since alfalfa grown on these farms maintained the soil nitrogen at or near these respective amounts, it might be considered that this is near the equilibrium level. In Cache Valley, where some of the virgin lands contained less nitrogen than those in Juab Valley, the maximum recovery by growing alfalfa amounted to 88.2 per cent of that lost. The nitrogen equilibrium level for land in alfalfa following wheat is considered to be approximately 7 per cent below adjacent virgin areas.

# EFFECTS OF FERTILIZER AND ROOTSTOCK ON TOTAL PHOSPHORUS CONTENT OF CITRUS FLOWERS

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Received for publication February 24, 1947

The flowering and fruit-setting processes in citrus trees are generally regarded as a severe drain on the reserve food materials in the tree. The blossom parts and most of the young fruits are normally shed during a period of heavy bloom, following which the trees appear to be lacking in thrift or vigor. The variations in the total nitrogen content of developing flowers and young fruits of Valencia orange were reported by Cameron and Appleman (1). These investigators pointed out that in full bloom the petals contained nearly half of the nitrogen content of the entire flower and that as the flowering season advanced there was a decrease in the nitrogen content that was suggestive of limitations in the supply of available nitrogen. Haas (3) has presented data that emphasize the heavy losses of nitrogen, ash constituents, and organic materials in citrus trees during the flowering and fruit-setting period. In a discussion of the relation of the mineral nutrition to the development of flowers, Loehwing (5) has pointed out that temporarily, at least, during the flowering process, the shoots are dependent largely upon their own residual supply of salts and that phosphorus and nitrogen are the elements most closely associated with the early stages of the transition from the vegetative to the reproductive phase. In the present paper attention is focused on the effects of fertilizers and rootstocks on the accumulation of phosphorus in citrus flowers. Changes in the phosphorus content of flowers as the flowering period advances are also pointed out, and some consideration is given to the problem of "June drop."

## MATERIALS AND METHODS

The flowers used for making any comparisons were collected at one time on the same day in order to avoid as much as possible large variations in depletions within the shoots of the trees. In collecting the samples it was necessary to obtain fully opened flowers without the loss of any of the petals and without contamination with other parts of the trees. The petiole or flower stalk was always included, whereas in very young fruits the button was always discarded.

The flowers were dried in a well-ventilated oven at 65°C. and were then ground to a powder in a micro Wiley mill. Three-fourths gram of powder was moistened with magnesium nitrate solution and was dried and then incinerated. This was repeated until a white powder was obtained. Nitric acid and distilled water were used in the solution, filtration, and bringing of the volume to 100 ml. One milliliter of this solution made up to 100 ml. volume was used in the determination of total phosphorus by means of a Fisher electro-photometer (4).

Large experimental solution, sand, and soil cultures as well as trees in the fertilizer plots and rootstock trials at the Citrus Experiment Station furnished the flowers used in this study. Pasture soil (Hanford loam) was screened and thoroughly mixed prior to its use in soil cultures. To avoid unnecessary details, only the pertinent facts regarding the culture solutions are included. When a range of nitrate concentration was obtained in a culture solution by the addition of calcium nitrate, the calcium in all culture solutions was balanced by the use of calcium sulfate solution. Distilled water was used in all cultures except the 110-liter soil cultures that received a culture solution containing a range of nitrate concentration every 1 or 2 days in amounts sufficient to give adequate drainage.

TABLE 1

*Effect of soil fertilization on the phosphorus content of flowers collected April 13, 1942, from Washington navel orange trees on sweet orange rootstock in the fertilizer plots at the Citrus Experiment Station, Riverside*

| FERTILIZER | PLOT | TOTAL PHOS-PHORUS IN DRY MATTER |
|---|---|---|
| | | *p.p.m.* |
| None; cover crop only | J4 | 4329 |
| None | L14 | 4114 |
| None; cover crop only | D12 | 4114 |
| Manure in fall, plus cover crop | D20 | 3614 |
| Urea, phosphate plus cover crop | H46 | 3029 |
| Urea plus cover crop | I6 | 2900 |
| Urea, sulfate of potash plus cover crop | H42 | 2871 |
| Calcium nitrate (3 pounds N) plus cover crop | D32 | 2757 |
| Calcium nitrate (5 pounds N) plus cover crop | D42 | 2757 |
| Nitrate of soda plus cover crop | K14 | 2643 |
| Ammonium sulfate (3 pounds N) plus cover crop | D46 | 2457 |

EFFECT OF FERTILIZERS

*Nitrogen*

Flowers were collected from Washington navel orange trees on sweet orange rootstock grown in the fertilizer plots at the Citrus Experiment Station. The trees in these plots were uniform as regards both the scion and rootstock origin. The data in table 1 show that the phosphorus contents of the dry matter of the flowers were highest when no nitrogen was added or when only cover crops were turned under. The lowest phosphorus values were obtained when nitrogen alone was applied to the soil and a cover crop was grown, or when these were supplemented with potash. Intermediate values were obtained when phosphorus and nitrogen-containing fertilizers such as manure plus a cover crop or when urea together with phosphate and cover crop were used.

A comparison was made of the total phosphorus content of the dry matter of the flowers of Valencia orange trees on sour orange rootstock in undrained

soil cultures when equal amounts of total nitrogen (by analysis) in the form of finely ground steer manure and powdered ammonium sulfate were used as fertilizers. The manure was covered with the soil when added to the cultures in order to hasten its disintegration. In every case the flowers from the trees in soil that received manure contained the higher phosphorus. Comparable flower samples from the manured and ammonium-sulfate-treated cultures contained at different times of collection: 3,843 and 3,000; 3,614 and 2,643; 3,600 and 3,386; 4,829 and 2,214; and 3,800 and 3,357 p.p.m. phosphorus in the dry matter respectively.

Equal amounts of total nitrogen (by analysis) were added from time to time to 110-liter soil cultures without drainage and containing Valencia orange trees on sour orange rootstock. Steer manure or alfalfa, dried and finely ground, and also powdered ammonium nitrate were among the sources of nitrogen applied. The Valencia orange flowers (table 2) from the cultures that received manure had the highest phosphorus content; those from the ammonium-nitrate-treated cultures had the least; and those from the alfalfa-treated cultures were

TABLE 2

*Effect of equal amounts of nitrogen from different sources (as fertilizer for soil cultures of Valencia orange trees on sour orange rootstock) on the phosphorus content of the flowers*

| NUMBER OF FLOWERS | FERTILIZER | TOTAL PHOSPHORUS IN DRY MATTER |
|:---:|:---|:---:|
| | | *p.p.m.* |
| 30 | Steer manure . | 3243 |
| 50 | Alfalfa | 2473 |
| 50 | Alfalfa | 2386 |
| 50 | Ammonium nitrate . | 2000 |

intermediate. Two factors may account for the increased phosphorus content in the cultures that received organic sources of nitrogen: first, the organic matter contained phosphorus; and second, the organic sources of nitrogen were probably more slowly available than the inorganic sources.

A series of 110-liter containers provided with drainage and filled with pasture soil (Hanford loam) were planted to Valencia orange trees on sour orange rootstock. The cultures received a complete nutrient solution containing a range of nitrate concentration from 25 to 600 p.p.m. added in the form of calcium nitrate. The cultures were grown over a period of about 4 years. Large numbers of flower samples were collected and their phosphorus content determined.

In a typical collection made on April 10, 1946, at the lowest nitrate concentration, the phosphorus content was found to be the highest—5,720 p.p.m. in the dry matter of the whole flowers. With 125 p.p.m. of nitrate, the phosphorus value was 3,100 p.p.m., whereas in a composite flower sample from the 450, 550, and 600 p.p.m. nitrate concentrations, the lowest phosphorus content (2,380 p.p.m.) was found.

A complete nutrient solution containing a range of nitrate concentration, added in the form of calcium nitrate, was used in growing rooted Valencia orange cuttings in large drained-pail-containers filled with pasture soil. At a concentration of 75 p.p.m. nitrate in the nutrient solution the dry matter in the flowers contained 3,457 p.p.m. of total phosphorus; at the 150-p.p.m. nitrate level the phosphorus value dropped to 3,171 p.p.m.; and at the 450-p.p.m. nitrate level the phosphorus value decreased to 2,529 p.p.m.

Eureka lemon trees were grown on sour orange rootstock in drained 110-liter soil cultures that received a culture solution containing a range of nitrate concentration through the addition of calcium nitrate to the solution. Flower collections were made after the trees were several years old. As shown in table 3, the phosphorus content of the flowers, collected on April 10, 1944, decreased as the nitrate concentration of the nutrient solution increased to 250 p.p.m.,

TABLE 3

*Effect of a range of nitrate concentration in a culture solution on the phosphorus content of flowers of Eureka lemon trees on sour orange rootstocks grown in large soil cultures*

| NITRATE CONCENTRATION IN THE CULTURE SOLUTION | NUMBER OF FLOWERS IN SAMPLES | TOTAL PHOSPHORUS IN DRY MATTER |
|:---:|:---:|:---:|
| *p.p.m.* | | *p.p.m.* |
| 25 | 23 | 2814 |
| 50 | 34 | 3186 |
| 150 | 34 | 2543 |
| 250 | 50 | 2057 |
| 350 | 50 | 2143 |
| 450 | 50 | 2243 |
| 550 | 50 | 2343 |
| 600 | 50 | 1900 |

after which the phosphorus content increased somewhat as the nitrate concentration increased to 550 p.p.m.

Valencia orange trees on sour orange rootstock were grown for several years in solution cultures in 110-liter containers. A complete nutrient solution containing a maintained range of nitrate concentration, brought about by the use of calcium nitrate, was used in these cultures. Four collections of flowers were made during 1942 and one during 1943. At every sampling the phosphorus content decreased as the nitrate concentration in the culture solution increased from 100 to 500 p.p.m. (table 4). Also at each nitrate concentration in the culture solution in the 1942 collections, the phosphorus content in the flowers decreased as the flowering season progressed. The same trend was found by Cameron and Appleman (1) for nitrogen in citrus flowers obtained by successive collections of flowers from orchard trees.

Trees similar to those used in these solution cultures were grown for several years in drained 110-liter containers filled with soil. During this time the soil was given a complete culture solution having as its variable a range of nitrate concentration. A number of flower collections were made from certain of these

soil cultures.  As shown in table 5, the phosphorus content of the flowers decreased as the season advanced.  The trend is evident in table 5 when the four collections were made within the relatively short period of 8 days.

The relation of nitrogen fertilization to the phosphorus content of flowers of Washington navel orange trees on sweet orange rootstock is shown in table 6. The flowers were collected on April 18, 1945, from basined trees in the orchard

TABLE 4

*Effect of nitrate concentration in large solution cultures of Valencia orange trees on sour orange rootstock and of the date of flower sampling on the phosphorus content of citrus flowers*

| CULTURE NUMBER | NITRATE IN SOLUTION CULTURE | FLOWER SAMPLING April 3, 1942 | | FLOWER SAMPLING April 6, 1942 | | FLOWER SAMPLING April 11, 1942 | | FLOWER SAMPLING April 14, 1942 | | FLOWER SAMPLING April 12, 1943 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of flowers | Total P in dry matter | Number of flowers | Total P in dry matter | Number of flowers | Total P in dry matter | Number of flowers | Total P in dry matter | Total P in dry matter |
| | *p.p.m.* | | *p.p.m.* | | *p.p.m.* | | *p.p.m.* | | *p.p.m.* | *p.p.m.* |
| 13 | 100 | 31 | 2286 | 80 | 2314 | 50 | 2057 | 100 | 1943 | 2057 |
| 14 | 250 | 10 | 2157 | 92 | 1986 | 26 | 1900 | 80 | 1643 | 1986 |
| 15 | 500 | 36 | 2000 | 109 | 1743 | 50 | 1614 | 100 | 1486 | 1714 |
| 16 | 750 | 35 | 2386 | 100 | 2143 | 50 | 1886 | 80 | 1686 | 2186 |
| 17 | 1000 | 60 | 1900 | 95 | 1757 | 60 | 1543 | 80 | 1486 | 2029 |
| 18 | 1250 | 50 | 2286 | 110 | 1914 | 60 | 1857 | 80 | 1714 | 2757 |

TABLE 5

*Seasonal decrease in the phosphorus content of flowers of Valencia orange trees on sour orange rootstock grown in soil cultures*

| NITRATE IN CULTURE SOLUTION | TOTAL PHOSPHORUS IN DRY MATTER | | | |
|---|---|---|---|---|
| | Flower sampling April 7, 1942 | Flower sampling April 11, 1942 | Flower sampling April 13, 1942 | Flower sampling, April 15, 1942 |
| *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| 50 | 2429 | 2429 | 2314 | 2186 |
| 75 | 2443 | 2400 | 2314 | 2229 |
| 550 | 2529 | 2386 | 2271 | 2171 |
| 600 | 2713 | 2400 | 2471 | 2300 |

of the Division of Irrigation and Soils at the Citrus Experiment Station, Riverside, California.  The basins of two of the trees received no nitrogen for the 2 prior years, whereas the basins of the other three trees received nitrogen in extra large quantity.  As shown in table 6, when no nitrogen was applied to the soil, the phosphorus content of the dry matter of the flowers was much higher than when the soil basins were heavily fertilized with nitrogen.  Mature fruits were obtained[1] from the trees in these soil basins, and the centrifuged and filtered juice was analyzed for N, P, and K.  The data in table 6 indicate that with

[1] These fruits were obtained through the kindness of M. R. Huberty, of the Division of Irrigation and Soils, University of California.

heavy nitrogen fertilization of the soil, the orange juice contained increased nitrogen and decreased phosphorus.

## Potassium

Low nitrogen concentrations in the nutrient medium were generally accompanied by an increased phosphorus content in citrus flowers. It is of interest to determine whether, with low concentrations of potassium in the cultures, the flowers likewise contain an increased phosphorus content. For this purpose rooted Valencia orange cuttings were grown in 110-liter sand cultures. These received a complete culture solution but containing a relatively low

TABLE 6

*Effect of excessive nitrogen fertilization on the phosphorus content of flowers from Washington navel orange trees on sweet orange rootstock and on the nitrogen, phosphorus, and potassium content of the juice of the mature oranges*

| | | | ORANGE JUICE | | | ORANGE FLOWERS | | |
| FERTILIZER PER SOIL BASIN | ROW | TREE | Total phosphorus | Total potassium | Total nitrogen | Total phosphorus in dry matter | Fresh weight | Dry weight |
|---|---|---|---|---|---|---|---|---|
| | | | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *gm.* | *gm.* |
| No nitrogen added for 2 years | 22 | 1 | 206.0 | 1937 | 1056 | 3571 | 128.5 | 23.2 |
| No nitrogen added for 2 years | 23 | 1 | 208.1 | 1863 | 1158 | 3571 | 137.2* | 24.1 |
| Wheat flour 150 pounds, Nitrate of soda 42 pounds, dug in 4 inches Feb. 16, 1944 | 13 | 1 | 176.6 | 1975 | 1359 | 2586 | 130.0 | 22.0 |
| Wheat flour 150 pounds, Nitrate of soda 42 pounds, dug in 4 inches Feb. 16, 1944, Ferrous sulfate 100 pounds applied to soil surface | 13 | 3 | 150.4 | 1880 | 1443 | 2400 | 115.0 | 21.1 |
| Steer manure 150 pounds | 13 | 4 | 173.4 | 1882 | 1414 | 2529 | 129.2 | 21.9 |

\* 100 flowers = 45.5 gm. fresh weight.

range of potassium concentration: (cultures 1 to 7 inclusive) 0.1, 1.0, 3.0, 6.6, 10.0, 15.0, and 50.0 p.p.m. of potassium respectively. The cuttings were planted in April, 1941, and between March 16 and April 9, 1943, produced in cultures 1 to 7 inclusive: 1, 15, 147, 152, 511, 724, and 166 flowers respectively. On April 7, 1944, cultures 1 to 7 inclusive produced 4, 3, 32, 933, 1289, 2328, and 2473 flowers respectively. The number of flowers generally increased as the potassium in the culture solution was increased, although no claim is made regarding the adequacy of any of these low-potassium concentrations. Table 7 gives the phosphorus content of the flowers collected from these Valencia orange cuttings grown at different potassium levels. The total phosphorus in the dry

matter of the flowers decreased as the potassium in the culture solution increased. It is also clearly shown for the flowers of cultures 6 and 7 that the phosphorus content in the flowers decreased as the flowering season advanced.

Valencia orange trees on Brazilian sour orange rootstock were used in 110-liter solution cultures, in which the culture solutions were all alike except for the low range of potassium concentration: 6.25, 12.5, 18.8, 25.0, 31.3, and 37.5 p.p.m. respectively. The phosphorus contents of the dry matter of the flowers collected on April 7, 1942 from the cultures having this range of potassium concentration were: 3,286, 2,300, 1,786, 2,186, 2,114, and 2,200 p.p.m. respectiveyl, the highest phosphorus value occurring at the lowest potassium concentration. Analysis of flower samples collected 7 days later showed that the phosphorus values for the two lowest potassium concentrations had dropped to 2,943 and 1,914

TABLE 7

*Effects of potassium concentration in the culture solution applied to 110-liter sand cultures of rooted Valencia orange cuttings and of the progress of the flowering season on the phosphorus content of Valencia orange flowers*

| CUL-TURE NUMBER | POTAS-SIUM IN CUL-TURE SOLU-TION | FLOWER SAMPLING April 4, 1946 | | | | FLOWER SAMPLING April 9, 1946 | | | | FLOWER SAMPLING April 15, 1946 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of flowers | Fresh weight | Dry weight | Total phosphorus in dry matter | Number of flowers | Fresh weight | Dry weight | Total phosphorus in dry matter | Number of flowers | Fresh weight | Dry weight | Total phosphorus in dry matter |
| | *p.p.m.* | | *gm.* | *gm.* | *p.p.m.* | | *gm.* | *gm.* | *p.p.m.* | | *gm.* | *gm.* | *p.p.m.* |
| 3* | 3.0 | | | | | | | | | | | | |
| 4 | 6.6 | | | | | | | | | 82 | 34 | 6.0 | 1809 |
| 5 | 10.0 | | | | | | | | | 237 | 188 | 16.5 | 2520 |
| 6 | 15.0 | 151 | 71 | 12.0 | 2380 | 261 | 103 | 20.3 | 2200 | 347 | 105 | 21.0 | 1980 |
| 7† | 50.0 | 127 | 58 | 10.8 | 1960 | 253 | 87 | 18.4 | 1720 | 274 | 79 | 17.2 | 1590 |

* Culture 3: May 1, 1946, 51 flowers, 16 gm. fresh weight, 3740 p.p.m. phosphorus.

† Cultures 5, 6, 7 composited April 19, 1945, 50 flowers, 23 gm. fresh weight, 4.3 gm. dry weight, 1170 p.p.m. phosphorus.

p.p.m. respectively while the value 2,114 had dropped to 1,619 p.p.m. These changes suggest a decreasing phosphorus concentration in the flowers as the flowering season advances.

. Valencia orange trees on sour orange rootstock were also grown in 10-gallon drained soil cultures that received a culture solution covering a range of potassium concentration. Flowers were collected on April 2 and again on April 9, 1946, from the soil cultures that received 150 and 300 p.p.m. of potassium respectively. The total phosphorus contents in the dry matter of the flowers collected on April 2 were 3,290 and 2,970 p.p.m. respectively, whereas on April 9 the corresponding values had decreased to 2,840 and 2,370 p.p.m. respectively. The data show that an increase in the potassium concentration in the culture solution applied to the soil cultures was accompanied by a decrease in the phosphorus content of the dry matter of the flowers, and they also show

that the phosphorus content of the flowers from a given culture decreased as the flowering season progressed.

### Phosphorus

A range of phosphate concentration was used in a given culture solution (pH about 4.5) for 110-liter drained soil cultures in which were grown Valencia orange trees on sour orange rootstock. As shown in table 8 a collection of flowers was made on April 19, 1945, and on April 4, 1946, from both the control culture that received no phosphate and the culture that received the highest phosphate concentration (67.2 p.p.m. $PO_4$). In each collection the flowers from the culture that received phosphate contained slightly more phosphorus than the flowers from the control culture.

### "June drop"

Data regarding the inorganic composition of the flowers or of very young navel orange fruits were found to offer no explanation for the occurrence of

TABLE 8

*Effect of phosphate in the culture solution applied to 110-liter soil cultures upon the total phosphorus in flowers of Valencia orange trees on sour orange rootstock*

| FLOWER SAMPLING DATES | NUMBER OF FLOWERS COLLECTED | PO4 IN CULTURE SOLUTION APPLIED TO SOIL | FLOWERS | | | TOTAL PHOSPHORUS IN DRY MATTER |
|---|---|---|---|---|---|---|
| | | | Fresh weight | Dry matter | Dry matter in fresh weight | |
| | | *p.p.m.* | *gm.* | *gm.* | *per cent* | *p.p.m.* |
| April 19, 1945 | 75 | 0 | 30.0 | 4.5 | 15.00 | 3000 |
| April 19, 1945 | 75 | 67.2 | 35.5 | 5.9 | 16.62 | 3500 |
| April 4, 1946 | 69 | 0 | 35.2 | 5.2 | 14.77 | 3000 |
| April 4, 1946 | 103 | 67.2 | 50.0 | 8.0 | 16.00 | 3180 |

"June-drop." Slightly off-color young fruits that were in the incipient stages of "June-drop" and also healthy fruits of approximately the same size as the affected fruits, were collected from the same trees in field S1A in a comparable manner on June 21 and 28 respectively in 1938. Table 9 indicates that a deficiency in the total as reducing sugars rather than a deficiency in the inorganic constituents may be involved in the "June-drop" of young orange fruits. Once the growth rate is slowed, then the increased water loss per unit volume in small as compared with larger-sized young fruits (2) may accelerate the "June-drop." Further study will be needed to determine whether "June-drop" in the fruits that result from late bloom is more severe than that in fruits from early bloom and in fruits that result from flower clusters rather than from widely separated single flowers.

#### EFFECT OF ROOTSTOCK ON PHOSPHORUS CONTENT

Some preliminary tests were made with orange flowers collected from seedling trees and from combinations of sweet orange as scions on sour and sweet orange as rootstocks in the pathology Plots in field 12. Table 10 indicates

slightly lower phosphorus content of the flowers of sour orange seedling trees than of those of sweet orange seedling trees. The flowers of Valencia orange had a higher phosphorus content when the scion was on sweet orange rather than on sour orange rootstock. Unfortunately at the time this tree planting

TABLE 9

*Composition of healthy Washington navel orange fruits as compared with that of similar-sized fruits affected with incipient stages of "June-drop" and collected from the same trees in field S1A*

| DATE OF YOUNG FRUIT COLLECTION | CONDITION OF YOUNG FRUITS | NUMBER OF FRUITS | FRESH WEIGHT | DRY WEIGHT | DRY MATTER IN FRESH WEIGHT | COMPOSITION OF DRY MATTER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ca | Mg | K | Reducing sugars | Total as reducing sugars | Total nitrogen | Total phosphorus | Boron Water-soluble | Boron Water-insoluble |
| 1938 | | | gm. | gm. | per cent | per cent | per cent | per cent | per cent | per cent | per cent | p.p.m. | p.p.m. | p.p.m. |
| June 21 | H* | 47 | 102.7 | 28.9 | 28.14 | 0.81 | 0.19 | 1.19 | | | | 2670 | 20.4 | 11.8 |
| June 21 | D† | 45 | 92.0 | 25.7 | 27.93 | 1.03 | 0.20 | 1.20 | | | | 2720 | 20.8 | 11.6 |
| June 28 | H* | 99 | 324.9 | 88.2 | 27.15 | 0.98 | 0.21 | 1.17 | 3.24 | 5.82 | 2.034 | | 21.3 | 9.5 |
| June 28 | D† | 99 | 316.2 | 85.9 | 27.17 | 1.01 | 0.20 | 1.12 | 3.34 | 4.58 | 2.015 | | 17.0 | 11.6 |

* Healthy
† Incipient stages of "June-drop."

TABLE 10

*Phosphorus content of flowers of seedling orange trees and of sweet orange on sour or sweet orange rootstocks in field 12 (Pathology Plots)*

| DATE OF FLOWER COLLECTION | NUMBER OF FLOWERS | SCION | ROOTSTOCK | ROW | TREE NUMBER | TOTAL PHOSPHORUS IN DRY MATTER |
|---|---|---|---|---|---|---|
| 1945 | | | | | | p.p.m. |
| May 1 | 140 | Seedling | Sour orange | 21 | 23 | 2257 |
| May 1 | 125 | Seedling | Weldon sweet orange | 28 | 15 | 3000 |
| May 4 | 125 | Seedling | Sour orange | 22 | 20 | 2420 |
| May 4 | 130 | Parson Brown (sweet orange) | Sweet orange | 28 | 24 | 2612 |
| Apri. 17 | 110 | Seedling | Sweet orange | 29 | 11–15 | 2729 |
| April 17 | 115 | Seedling | Sweet orange | 28 | 1–5 | 2829 |
| April 20 | 130 | Valencia orange | Sour orange | 20 | 17–20 | 2671 |
| April 20 | 130 | Valencia orange | Sweet orange | 20 | 6, 8, 9, 10 | 3114 |

was made, little or no distinction was made between the various strains of sweet or sour orange as rootstocks.

Preliminary tests were also made of the phosphorus content of flowers collected November 18, 1946, from Eureka lemon trees on various rootstocks planted in 1931 in field S1A. In row 14, trees 6–10, the dry matter of flowers of Eureka lemon on Camulos grapefruit as rootstock contained 2,743 p.p.m. total phosphorus; for Paraguay sour orange as rootstock (row 15, trees 1–5) the value was

2,643 p.p.m.; and for Palestine sweet lemon as rootstock (row 15, trees 6–10) the value was 2,471 p.p.m. Table 11 shows clearly that the flowers of Eureka lemon on grapefruit rootstock had the highest phosphorus content and on sweet lemon rootstock the lowest phosphorus content, as these preliminary data would indicate.

Other preliminary tests were made with Eureka lemon flowers also collected November 18, 1946, from trees planted in 1940 in field 3. On Sampson tangelo rootstock (row 35) the phosphorus value obtained was 2,743 p.p.m. while for the same rootstock (row 34) the value was 2,600 p.p.m.; on Brazilian sour orange (row 32) the value was 2,714 p.p.m., and on Bessie sweet orange (row 31) 2,671 p.p.m.

TABLE 11

*Phosphorus content of flowers collected December 10, 1946, from Eureka lemon trees on various rootstocks in field 3 at the Citrus Experiment Station, Riverside, California*

| ROOTSTOCK | BLOCK | ROW | TREES | TOTAL PHOSPHORUS IN DRY MATTER |
|---|---|---|---|---|
| | | | | *p.p.m.* |
| Sampson tangelo.................... | C | 23 | 11–15 | 3321 |
| C.E.S. #343 grapefruit.............. | B | 21 | 1–5 | 3071 |
| Duncan grapefruit.................. | B | 23 | 1–5 | 2964 |
| Bessie sweet orange................. | C | 12 | 1–5 | 2929 |
| C.E.S. #343 grapefruit.............. | B | 36 | 6–10 | 2857 |
| Bessie sweet orange................. | B | 10 | 1–5 | 2732 |
| Rubidoux sour orange............... | B | 29 | 1–5 | 2732 |
| Madam Vinous sweet orange......... | C | 13 | 1–5 | 2714 |
| Rubidoux sour orange............... | C | 11 | 1–5 | 2643 |
| Cleopatra mandarin................. | B | 35 | 6–10 | 2625 |
| Rough lemon....................... | C | 14 | 1–5 | 2571 |
| Madam Vinous sweet orange......... | B | 28 | 6–10 | 2554 |
| Brazilian sour orange............... | B | 28 | 1–5 | 2500 |
| Cleopatra mandarin................. | C | 13 | 6–10 | 2429 |
| Sweet lemon....................... | C | 17 | 6–10 | 2411 |
| Sampson tangelo.................... | B | 38 | 6–10 | 2232 |
| Rough lemon....................... | B | 26 | 1–5 | 2196 |
| Brazilian sour orange............... | C | 15 | 1–5 | 2107 |

*Eureka lemon on various rootstocks*

At the time (November 18, 1946) the flower samples were collected for the preliminary tests, the number of flowers available were limited in the orchard, and therefore further collections were delayed until the flowering was abundant. On December 10, 1946, large collections of Eureka lemon flowers were made from trees on the various rootstocks in field 3 at the Citrus Experiment Station. In table 11 the rootstock variety is listed according to the magnitude of the phosphorus content in the Eureka lemon flowers. The block, row, and tree numbers give some notion of the distribution of the plots and therefore of the samples throughout the orchard. The results obtained strongly indicate that when factors such as scion variety, soil medium, and fertilization are alike, the

rootstock variety is found to have an effect on the phosphorus accumulation in lemon flowers.

As shown in table 11, the grapefruit and Bessie sweet orange rootstocks occur near the top of the list, whereas Brazilian sour orange, sweet lemon, rough lemon, and Cleopatra mandarin occur at the lower end of the list. Not all sour orange rootstock varieties behaved alike. The values for the Sampson tangelo rootstock gave no indication of uniformity.

TABLE 12

*Rootstock effect on the phosphorus content of flowers collected April 17, 1945, from Valencia orange trees on various rootstocks in field S1A at the Citrus Experiment Station, Riverside, California*

| ROOTSTOCK | ROW | TREE | DRY MATTER IN FRESH WEIGHT OF FLOWERS | DRY MATTER PER FLOWER | TOTAL PHOSPHORUS IN DRY MATTER |
|---|---|---|---|---|---|
| | | | *per cent* | *gm.* | *p.p.m.* |
| Trifoliate orange.................... | 22 | 6–9 | 17.65 | .0900 | 3543 |
| Trifoliate orange.................... | 21 | 1–5 | 17.65 | .0900 | 3486 |
| Savage citrange..................... | 22 | 1, 2, 4, 5 | 15.79 | .0720 | 3486 |
| Savage citrange..................... | 23 | 6–10 | 16.98 | .1030 | 3403 |
| Sampson tangelo.................... | 31 | 6–10 | 16.25 | | 3346 |
| Cleopatra mandarin................. | 32 | 11–15 | 16.67 | .0800 | 3332 |
| Duncan grapefruit.................. | 31 | 1–5 | 16.67 | .0898 | 3329 |
| Cleopatra mandarin................. | 31 | 11–15 | 16.27 | .0883 | 3218 |
| C.E.S. # 343 grapefruit............. | 36 | 11–15 | 15.81 | .0877 | 3218 |
| Sampson tangelo.................... | 30 | 6–10 | 18.13 | .0971 | 3214 |
| Siamese shaddock................... | 32 | 1–5 | 16.94 | .0953 | 3117 |
| Siamese shaddock................... | 35 | 11–15 | 15.79 | .0800 | 3117 |
| C.E.S. # 343 grapefruit............. | 33 | 1–5 | 18.13 | | 3117 |
| Duncan grapefruit.................. | 34 | 11–15 | 16.63 | .0792 | 3114 |
| Rough lemon....................... | 30 | 1–5 | 19.18 | .1031 | 3032 |
| Koethen sweet orange.............. | 35 | 1–5 | 19.13 | | 3017 |
| African sour orange................ | 30 | 11–15 | 17.01 | .0870 | 2971 |
| C.E.S. # 362 sweet orange.......... | 36 | 1–5 | 18.74 | | 2886 |
| Koethen sweet orange.............. | 28 | 6–10 | 17.81 | .0923 | 2831 |
| Rough lemon....................... | 32 | 6–10 | 18.03 | .1223 | 2803 |
| African sour orange................ | 27 | 1–5 | 17.03 | .0843 | 2746 |
| C.E.S. # 362 sweet orange.......... | 29 | 6–10 | 17.74 | .0880 | 2686 |
| Rubidoux sour orange.............. | 33 | 6–10 | 16.15 | .0855 | 2600 |
| Brazilian sour orange.............. | 29 | 1–5 | 17.67 | .0912 | 2600 |
| Lemon shaddock................... | 33 | 11–13 | 18.65 | .0928 | 2529 |

*Valencia orange on various rootstocks*

Flowers were collected April 17, 1945, from Valencia orange trees on various rootstocks in field S1A. The percentages of dry matter in the fresh weights of the flowers are given in table 12. Rough lemon, Koethen sweet orange, and C.E.S. # 362 sweet orange rootstocks produced flowers with the highest percentages of dry matter, whereas sour orange rootstock gave intermediate values. The values for both African sour orange rootstocks show good agreement, as do the values for Cleopatra mandarin and for Duncan grapefruit.

In table 12 the rootstocks are listed in descending order of the phosphorus found in the dry matter of the flowers collected from the Valencia orange scions. The table shows that the total phosphorus content of flowers of the scion is largely dependent on the nature of the rootstock variety when other factors are the same.

Trifoliate orange, Savage citrange, Cleopatra mandarin, Siamese shaddock, and the grapefruit rootstock varieties occur in the uppermost 14 of the 25 rootstocks listed. Rough lemon, sweet orange, sour orange, and lemon shaddock rootstock varieties comprise the lower 11 listed.

### SUMMARY AND CONCLUSIONS

Flowers from Washington navel orange trees on sweet orange rootstock in the fertilizer plots at the Citrus Experiment Station at Riverside, California, had the highest phosphorus content when no nitrogen was applied to the soil or when only cover crops were turned under.

When organic sources of nitrogen were compared with equal amounts of inorganic nitrogen, more phosphorus was found in the flowers of Valencia orange trees on sour orange rootstock in the soil organic nitrogen cultures. This may be due to the additional phosphorus contained in the organic matter, together with the slower availability of the organic nitrogen sources.

In soil cultures of Valencia orange or Eureka lemon trees on sour orange rootstock or in soil cultures with rooted Valencia orange cuttings that received a culture solution containing a range of nitrate concentration, the flowers had the highest phosphorus content when the nitrate concentration in the culture solution was lowest.

When four collections of flowers were made during April in 1942 from Valencia orange trees on sour orange rootstock in large solution cultures containing a range of nitrate concentration, it was found that the phosphorus content of the flowers decreased as the nitrate concentration in the culture solution increased from 100 to 500 p.p.m. At each nitrate concentration in the culture solution the phosphorus content of the flowers decreased as the flowering season progressed. The decrease in phosphorus content as the season advanced was also evident when the four collections of flowers were made within the short period of 8 days.

Use of excessive nitrogen fertilization in soil basins containing navel orange trees in the Experiment Station orchard resulted in a lowering of the phosphorus content in the flowers and also of the phosphorus content in the juice of the mature fruits.

A complete culture solution containing a range of potassium concentration, when used for citrus trees in solution, sand, or soil cultures, was found to reduce greatly the number of flowers produced as the potassium supply became most limited. The phosphorus content of the flowers decreased as the potassium in the culture solution increased, and the phosphorus content in the flowers also decreased as the flowering season advanced.

Only slightly higher phosphorus values were obtained in flowers from soil

cultures that received increased concentrations of phosphate in the culture solution.

No significant changes occurred in the inorganic composition in incipient stages of "June-drop" in young orange fruits, and there is a suggestion that a deficiency in the total sugar content together with excessive water loss may be factors involved in "June-drop" of young orange fruits.

When factors such as scion variety, soil, and fertilizer applications are similar, then it is more clearly seen that the rootstock variety is important in relation to the total phosphorus concentration of the dry matter of Eureka lemon flowers. Under these conditions the grapefruit and Bessie sweet orange rootstocks occur near the top of the list when the phosphorus contents are placed in descending order of magnitude. Brazilian sour orange, sweet lemon, rough lemon, and Cleopatra mandarin rootstocks occur in the lower part of the list. Not all sour orange rootstock varieties behaved alike.

The total phosphorus content of the dry matter of Valencia orange flowers was found to be largely dependent on the nature of the rootstock variety when factors such as the scion variety and soil environment (including fertilization) were the same. When the values for the total phosphorus content of the dry matter of the flowers were tabulated in a descending order of magnitude, the 14 uppermost of the 25 rootstocks listed included Trifoliate orange, Savage citrange, Cleopatra mandarin, Siamese shaddock, and grapefruit. The other rootstock varieties in the remainder of the list were rough lemon, sweet orange, sour orange, and lemon shaddock.

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# COLLECTION AND PRESERVATION OF SOIL PROFILES[1]

HENRY W. SMITH AND C. D. MOODIE[2]

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Despite the fact that numerous procedures have been described for collecting and preserving soil profiles, few educational agencies in this country have made maximum use of such materials. To promote their general employment in teaching and research, a procedure is needed which takes little special equipment and which can be used on a wide variety of soil types with slight variation from a basic technique. The final profile should be stable in a vertical position, thick enough to exhibit soil structure characteristics, and long enough to contain the entire soil profile. The method described here, which was adapted from the work of Voight[3], Storie[4], Lyford[5], Berger and Muckenhirn[6], and Harper[7], satisfies these requirements. Although the optimum moisture content is somewhat below the field capacity, soils of all textures have been sampled at moisture percentages varying from those of air-dry soils to those at the field capacity, without alteration of technique.

In the State of Washington about 400 profiles have been taken by this procedure. At the several Experiment Stations the collections are being employed primarily as teaching aids, as are those which have been collected by personnel of the Agricultural Extension Service, the Soil Conservation Service, and the Bureau of Reclamation. Also, in connection with a current research project on physical and chemical properties of the soils of Washington, a mounted profile, together with horizon samples for analysis, is taken from the wall of each pit. These profiles are helpful in the interpretation of laboratory data.

Examples of mounted profiles of soils of widely different physical characteristics are depicted in figure 1. Horizons shown include loose coarse gravels in the Springdale, a siliceous A₂ in the Chopaka, a lime-cemented hardpan in the Selah, and both prismatic and massive structures in the Nez Perce profile.

[1] Published as Scientific Paper No. 710, College of Agriculture and Agricultural Experiment Stations, Institute of Agricultural Sciences, State College of Washington, Pullman.

[2] Assistant professor and instructor in soils, respectively.

[3] Voight, E. Ein neues Verfahren zur Konservierung von Bodenprofilen. *Ztschr. Pflanzenernahr., Düngung, u. Bodenk.* **45**: 111–115. 1936.

[4] Collection of soil monoliths by the cellulose acetate method. Typed copy, dated October, 1941, supplied by R. E. Storie, University of California, Berkeley.

[5] Lyford, W. H., Jr. Preservation of soil profiles by Voight's method. *Soil Sci. Soc. Amer. Proc.* **4**: 355–357. 1939.

[6] Berger, K. C., and Muckenhirn, R. J. Soil profiles of natural appearance mounted with vinylite resin. *Soil Sci. Soc. Amer. Proc.* **10**: 368–370. 1945.

[7] Harper, H. J. A study of methods for the preparation of permanent soil profiles. Okla. Agr. Exp. Sta. Tech. Bul. 201. 1932.

## SOLUTIONS AND EQUIPMENT

1. *Cellulose acetate in acetone, dilute.* Prepare by dissolving about 140 gm. of cellulose acetate in sufficient acetone to make a gallon of solution.
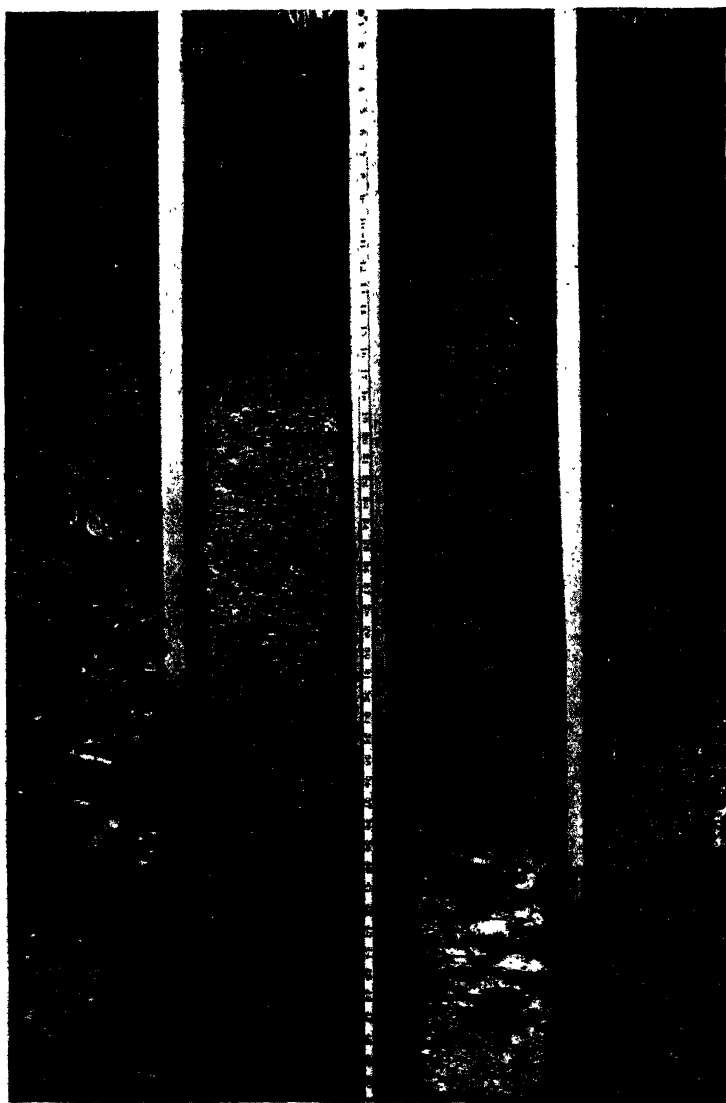


FIG. 1. PROFILES, FROM LEFT TO RIGHT, OF SPRINGDALE GRAVELLY LOAM, CHOPAKA SILT LOAM, SELAH LOAM, AND NEZ PERCE SILT LOAM, ALL MOUNTED IN THE FIELD

2. *Cellulose acetate in acetone, concentrated.* Prepare by dissolving about 450 gm. of cellulose acetate in sufficient acetone to make a gallon of solution.

3. *Vinylite resin in acetone-methyl isobutyl ketone.* Prepare by dissolving about

240 gm. of VYHH resin (Bakelite Corporation) in a mixture of acetone and methyl isobutyl ketone sufficient to make a gallon of solution. Adjust the basic solvent ratio of 2 to 1 according to the nature of the soil material, if desired.

Each of these materials will go into solution within a few days if the container is up-ended three or four times every day. The average profile will require 1 quart of dilute acetone-cellulose acetate solution, 3 pints of concentrated acetone-cellulose acetate solution, and 1 quart of vinylite resin solution. Glass 1-gallon jugs are convenient in the field. Five-gallon metal cans are used in preparing and shipping solutions.

4. *Two ⅜-inch boards*, 6 inches wide, one 4 feet and the other 6 feet long, or longer if necessary. Any quality of board is satisfactory, since they are used only for removing the profiles from the bank.

5. *Boards for mounting the profiles:* ½- to ¾-inch five-ply boards are best, although any board that is of good quality and that will not warp can be used; width should be 8 inches, and length at least 8 inches greater than that of the profile. The appearance of an exhibit is improved if only a few standard lengths are employed.

6. *Spray pump:* an all-metal or glass and metal pump which delivers a coarse spray is satisfactory. It can be used both for the dilute cellulose acetate and the vinylite resin solution. It should be rinsed with acetone after each period of use.

7. *Miscellaneous equipment:* cutter mattock, geologist's pick, stone mason's hammer, butcher knife, pocket or paring knife, metal rule, shovel, spade, cloth tying-strips about 2 inches wide, twine, and large sacks for wrapping the profiles in the field.

## COLLECTION OF SOIL PROFILES

### Preparation of exposure

Careful selection of the site is necessary if the profile is to be representative of a soil type and is not to exhibit such local features as excessive erosion or deposition. The excavation should be deep enough so the complete profile can be sampled. Prepare an approximately plane surface, which slopes about 5 degrees from the vertical. A slope in excess of this results in distortion of prismatic or columnar structures, whereas too little slope makes difficult the application of the concentrated solution of cellulose acetate. A flat spade is useful in working out friable soils, but a cutter mattock is essential in reducing the profile of a soil with a claypan or a hardpan to an approximately plane surface. The prepared strip should be about 2 feet wide for a single profile, but extreme care is necessary only in preparing the center strip of 6-inch width, which should be marked with a knife cut. If this cut is made to a depth of ¼ to ½ inch, the profile will be easier to shape after the solutions have been applied. Soils that have horizons of completely incoherent sand or gravel in the profile often must be prepared with a greater slope, to prevent slumping, and of course the boundaries of the strip cannot be marked as suggested. In figure 2 are illustrated the first steps in the preparation of the exposure.

*Initial spray*

Spray the prepared 6-inch section with the dilute solution of cellulose acetate as illustrated in figure 2. For a strip 6 inches wide and 6 feet long, about 1 quart of solution is necessary; the amount needed is variable according to the soil texture and structure. In dense and fine-textured soil, penetration will be negligible except along structural lines. Sands will be penetrated $\frac{1}{4}$ to $\frac{1}{2}$ inch, and incoherent gravels will be penetrated about 1 inch. This initial spray fixes the soil and makes possible the application of the concentrated solution of cellulose acetate.

*Cellulose acetate film*

The solvent used in the initial spraying will evaporate in 5 to 15 minutes, dependent on weather conditions and the water content of the soil. On all save incoherent soils, which should dry at least 30 minutes, the concentrated solution can then be applied with a brush, starting at the top. Do not try to "brush out" the solution, or the initial surface formed by the sprayed solution will be broken. Allow it to flow from the brush (fig. 2), or pour it directly from a container on the strip, using the brush merely to direct the downward flow of the solution. Force the solution into any holes or crevices present, so that a continuous film will result on the soil strip. No further work can be done until this film has hardened. Only the one coat should be applied; a second would dry slowly and make difficult the removal of the profile from the bank, while adding little to its final stability.

*Removal of profile from exposure*

Usually within 15 to 30 minutes after the concentrated solution is applied, drying will have progressed sufficiently that preliminary shaving of the edges of the profile can be started, except on incoherent soils. If more than a thin layer of soil material is wanted on the final profile, these latter soils should not be worked out until about an hour after the concentrated solution has been applied. Care must be used not to tear the film, which at this stage will be somewhat soft.

It is advisable to lay a 6-inch board over the painted strip to protect it while a trench 6 to 8 inches wide and 3 to 5 inches deep is being made on each side of the painted strip. The edge next to the profile should coincide with the original knife mark. It is preferable to start excavating the trench near the bottom of the profile. In this way, by the time one has excavated at either side the thick coat will have dried sufficiently that it will not be damaged if a few soil particles fall against it. Particles should not be allowed to collect on the coating in any quantity, however, while the trenches are being completed.

The profile is now ready to be removed from the bank. A satisfactory technique is to cut behind the full length of the profile, on one side only, to its approximate center, using either a knife or a geologist's pick. During the process it is preferable to reduce the thickness of the soil mass to not more than 3 inches for most soils and to even less for incoherent soils; otherwise the cellulose acetate film may break when the soil is transferred to the final supporting board. The

thickness of the profile at this stage will increase toward the center of the 6-inch strip. Parts of this procedure are illustrated in figure 3.



FIG. 2. LEFT, A PLANE SURFACE IS PREPARED ON AN EXPOSED BANK. CENTER, THE DILUTE CELLULOSE ACETATE SOLUTION IS SPRAYED ON THE MARKED STRIP. RIGHT, THE CONCENTRATED CELLULOSE ACETATE SOLUTION IS APPLIED WITH A BRUSH



FIG. 3. LEFT AND CENTER, SOIL MATERIAL IS WORKED OUT FROM BEHIND THE PROFILE AFTER THE TRENCHES HAVE BEEN COMPLETED. RIGHT, PROFILE IS READY TO BE PULLED FROM THE BANK

The loose soil at the base of the profile should now be removed, and the surface of the entire strip of film freed of soil particles. Replace the 6-inch board and align it with the edge of the film. Starting at the top, cut behind the profile from the other side at about 6-inch intervals, and tie strips of cloth around the

board and the soil column as each hole is broken through the soil mass behind the board. . It is usually wise to have these strips at 4- to 8-inch intervals, and to leave "bridges" of undisturbed soil between the strips. The more incoherent the soil, the more strips will be required, since the supporting bridges will not stay in place. If very large rocks are present these will need to be held by several cloth strips or by wide bands of cloth. An example of such a soil is Ephrata stony sandy loam shown in figure 6. Continue to work toward the base of the profile until it is tied firmly to the board (fig. 3). The bridges may then be cut or cracked loose and the board with its attached profile removed to a horizontal position (fig. 4). This step in the procedure is not difficult in the case of coherent soils. Those with incoherent layers may be troublesome until some experience has been acquired, since there is sometimes a tendency for the soil to slump unless it is tied securely to the board. It is often helpful to have two persons working on a single profile during this last step of removing it from the bank.

### Mounting the profile

Do not remove any large amount of the soil at the center of the profile even though it appears to be loose, but brush all free material from the edge of the board after the cloth strips are removed. Lay a second (8-inch) board on the ground beside the profile. Outline the desired position of the final soil column and pour some of the concentrated solution in a strip down the center of the board (fig. 4). Brush it out slightly, but do not try to coat the full 6-inch width with adhesive. One or two persons can pick up the profile and slide it on the new board (figs. 4 and 5). Care must be used not to scrape off the adhesive during this process. Straighten the profile on the board and press it down to ensure good contact (fig. 5). Wipe off any excess solution that may have squeezed from beneath the profile, for if this excess dries it can be removed only with difficulty. The transfer just described should always be performed promptly. If an hour or two separates the removal of the profile from the bank and its transfer to the final board, it may become stuck to the original 6-inch board.

There is always a temptation to work out the structure at this time. To do so is unwise, since the cellulose acetate has not yet hardened completely. It is preferable to wrap the profile with cloth and tie it with twine (fig. 5), after which it can be transported if it is kept in a horizontal position.

### Removal of excess soil

After about 24 hours the excess soil material can be removed, unless the profile was moist when it was taken. If so, it should be allowed to dry before further work is done. Soils with massive structures will be difficult to work down if they are left until the soil is completely air-dry, but horizons with prismatic, granular, or single-grain structure can be worked out with ease. Care should be used to remove pieces by breaking only along structural lines and to leave no knife marks on the finished profile. Repair work should be kept to a minimum, and all necessary work should be done with care. Otherwise, the profile will lose its natural appearance.

FIG. 5. TOP, TRANSFER OF PROFILE IS COMPLETED. CENTER, PROFILE IS CENTERED ON BOARD, AND PRESSED DOWN TO ENSURE GOOD CONTACT. BOTTOM, PROFILE IS WRAPPED, READY TO BE TRANSPORTED



FIG. 4. TOP, THE PROFILE IS REMOVED FROM THE BANK. CENTER, ADHESIVE IS APPLIED TO THE SECOND BOARD. BOTTOM, THE PROFILE IS TRANSFERRED TO THE FINAL BOARD

In soils of medium or fine texture, and with well-developed structure, loose excess material can be removed by standing the profile on its side and tapping the supporting board rather vigorously.   If this is done with coarse-textured soils having single-grain or pulverulent structure, however, the resulting profile will be thin and quite without character.   For these latter soils the supporting board should be tipped only slightly and the excess material removed by cautiously blowing or brushing it from the profile; a thickness of ½ to 1 inch of soil material can thus be maintained.   *It is not necessary that this soil material be firmly fixed to the board at this stage*, only that it be in its natural position and free of disturbed soil material, for it will be stabilized by the next process.
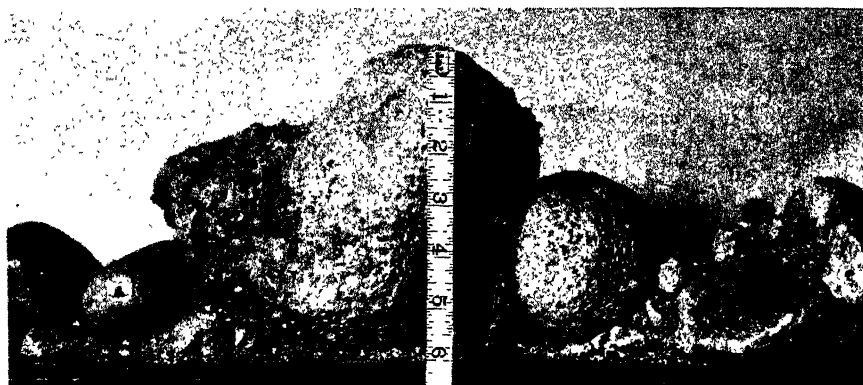


FIG. 6. PART OF A PROFILE OF EPHRATA STONY SANDY LOAM THAT HAD BEEN HANGING
VERTICALLY FOR 5 MONTHS.  NO PATCHING WAS REQUIRED EITHER
IN THE FIELD OR IN THE LABORATORY

## Finishing the profile

To prevent loss of material from the soil profile during future handling, and to develop an approximately moist-soil color, the soil is treated with vinylite resin by a procedure adapted from that of Berger and Muckenhirn.   A solution of approximately 8 per cent resin in a solvent mixture consisting of two-thirds acetone and one-third methyl isobutyl ketone will fix the soil material yet leave no visible residue if enough is sprayed on the soil nearly to saturate it.   If a sheen does develop after the solvent has evaporated, it can be removed by spraying some pure methyl isobutyl ketone on the soil surface.   To reduce the tendency for a surface gloss to appear, a higher proportion of methyl isobutyl ketone to acetone can be used in the preservative spray.   A somewhat "varnished" appearance of fine-textured horizons may be preferred by some, since it approaches that observed in the field when the soil is moist.   After the resin spray has hardened the edges of the board can be cleaned.   A coat of paint or varnish applied to the edge of the board will improve the appearance of the profile.

SUMMARY

In view of the considerable value of mounted soil profiles to those concerned with teaching and research, a detailed procedure has been described which per-

mits, with little special equipment and but slight modification of the basic technique, the taking of profiles at varying moisture content, of any reasonable length, and of sufficient thickness to exhibit structural characteristics. In the field, the soil is fixed with a dilute solution of cellulose acetate in acetone, backed by a tenaceous film of cellulose acetate, and glued to a board. The profile is worked down either in the field or in the laboratory and stabilized by spraying with a dilute solution of vinylite resin in mixed acetone and methyl isobutyl ketone. The resulting mounted profile resembles the field profile in all features, including color, and is stable in the vertical position.

# CAPILLARY RISE OF MOISTURE IN SOIL UNDER FIELD CONDITIONS AS STUDIED BY THE ELECTRICAL RESISTANCE OF PLASTER OF PARIS BLOCKS[1]

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Received for publication March 27, 1947

Capillary rise of moisture in soils has received a great deal of study, undoubtedly because of its important role, that of lifting and supplying moisture to the plants and to the evaporation forces. As related to plants, the main practical issues involved have been: under what conditions does capillary rise lift water to the root zone or to upper soil layers, from what possible depth, at what rate, and to what extent.

Most of the study on the subject seems to have been done in the laboratory with soils in tubes where experimental conditions could be better controlled. Some investigations have also been conducted, however, under field conditions, but the number of these performed under controlled conditions is very limited and the results have been inconclusive.

One of the greatest handicaps in the study of capillary rise of moisture in soils has been lack of a good, suitable method. Presumably for this reason, actual field data are very limited and the conclusions drawn are in the main conflicting, indefinite, and incomplete. They lead to the conclusion that the subject needs to be approached from a new angle.

Development of the plaster of paris block electrical resistance method[2] seems to have presented an ideal means of studying the capillary rise of moisture in soils under field conditions. This is because: 1. The method is capable of giving a continuous measurement of soil moisture, without disturbing the soil and the plants. 2. The method is capable of measuring both the total and the available water content. 3. By placing plaster of paris blocks at different depths in the field soil, one can readily trace the development of a moisture gradient and the capillary rise of the moisture at various depths. 4. Since the method can be used to measure the permanent wilting point of soils and to distinguish between total and available water content, it is possible to ascertain the rate and extent of movement of these different conditions of water. 5. The method makes it possible to study any possible moisture movement at or below the permanent wilting point of soils. 6. The experimental data yielded by the method can, when properly calibrated, be quantitatively treated from the soil-moisture free-energy concept.

[1] Contribution from the Soil Science Section of the Michigan Agricultural Experiment Station. Authorized by the director for publication as Journal Article No. 861 (N.S.).

[2] Bouyoucos, G. J., and Mick, A. H. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Mich. Agr. Exp. Sta. Tech. Bul. 172. 1940.

Bouyoucos, G. J., and Mick, A. H. Improvements in the plaster of paris absorption block electrical resistance method for measuring soil moisture under field conditions. *Soil Sci.* 63: 455–465. 1947.

The object of this paper is to present a study of the capillary rise of moisture of soils under field conditions as measured by the plaster of paris block electrical resistance method.

The method used in studying the capillary rise of moisture in field soil was to grow plants in the soil in order to reduce its moisture content to different levels at various depths and thus create a moisture gradient, harvest the crop, cover the soil to prevent loss of moisture by evaporation, then study the resupply of moisture to the dry layers.

To accomplish this objective the following procedure was adopted. A hole was dug in the field soil 3½ feet deep and 3½ feet in diameter. Into this hole was placed a metal tank 3 feet deep and 3 feet in diameter, without bottom and top, but with watertight sides. This tank was then filled with the 6-inch surface layer of soil which had been previously screened and thoroughly mixed so that the entire soil column in the tank was very uniform.

Six such soil tanks were prepared and placed in different locations in three different fields. The location was determined by the depth of the water table. This depth was a paramount consideration in view of its bearing on the capillary rise and the moisture gradient in the soil column. Tanks 1 and 2 were placed in low ground where the water table in summer stood at 3 to 5 feet from the surface and could rise to the surface in a heavy rain, as it did in August, 1940. Tanks 3 and 4 were placed in medium-high ground where the water table in summer usually stood at 4 to 6 feet from the surface. Tanks 5 and 6 were located on high ground where the water table was deep.

Tanks 1 and 3 were filled with clay loam; tanks 2, 4, and 6 with sandy loam; and tank 5 was filled with silt loam.

By using a water table of different depths and soils of different textures it was thought that a more comprehensive study would be afforded the problem.

The soils in all tanks were exposed to the weather and allowed to settle for more than a year. Then in the center of the soil column in each tank were placed four plaster of paris blocks at depths of 6, 12, 24, and 36 inches. After an additional time was allowed for the blocks and the soil to settle and reach some degree of equilibrium, corn was planted. The corn was allowed to grow as normally as possible. While the corn was growing, measurements of the soil moisture were made by taking electrical resistance readings of the blocks at the various depths. When the corn had grown considerably and had reduced the moisture content to various levels down to the 24- and 36-inch depths so there was a pronounced moisture gradient, as indicated by the block resistance, the crop was harvested and the tanks were covered.

Each tank was covered by placing a sheet of cellophane over the surface soil and then placing on the top of the tanks a wide, long sheet of galvanized iron which served to shed the rain and to protect the soil from the sun and wind. It is believed that these measures minimized evaporation losses after the plants had been removed.

Meanwhile, the electrical resistance of the moisture blocks in the covered tanks was measured frequently to ascertain the behavior and capillary movement of the soil moisture.

For information on the total water content and the total amount of available moisture in each soil at the various moisture levels and at the different depths, the blocks were calibrated for each soil. This calibration afforded a means of estimating the amount of the total water or of the available water that moved from one depth to another within a given time. It is well to bear in mind that a block resistance of about 500 ohms represents field capacity and a block resistance of 60,000 ohms represents wilting point. All block resistance readings were corrected to the temperature of 70° F.

This experiment was started in 1939 and has been continued for several years. In this paper only the results for 1940 and 1941 are presented. Important observations and essential conclusions from the data of other years are also included.

## EXPERIMENTAL RESULTS

The results obtained for each tank for each year are presented in figures 1 to 12. A calibration in terms of percentage of total water and of available water content at the various block resistances is given for each soil. Each graph also shows the inches of rainfall for the months during which the experiment was in active operation.

The graphs for the 2 years' trials in the various tanks bring out the following outstanding facts:

1. By the time the corn was harvested and the tanks were covered, a very marked and variable moisture gradient had been created in all the different tanks, thus affording the capillary forces a very wide range on which to operate in moving soil moisture from one water level to another. It will be seen that in some tanks the moisture content had been reduced by the corn from considerably beyond the wilting point at the 6-inch depth to field capacity at the 36-inch depth. In other tanks, the moisture had been reduced to the wilting point and beyond, all the way down to the 36-inch depth.

2. August, 1940, was very wet, with almost 10 inches of rainfall. This caused the water table to rise, particularly in the low land where tanks 1 and 2 were. The water table in this field rose rather rapidly and came to within 1 inch of the surface. It was the rise of the water table, therefore, that wetted the soils in tanks 1 and 2 and caused the block resistance to fall precipitously. It will be seen that the block resistance in these two tanks fell to field capacity or saturation point very quickly. The water table rose in August, 1940, also to wet the 36-inch depth in tanks 4 and 6, which were on higher ground. The 36-inch depth in tank 3 was not affected greatly, however, by the water table or capillary rise. Nor were the upper depths in tanks 3, 4, 5, and 6 affected by the water table or capillary rise in that same year.

3. Where the water table did not rise to wet the soil by very close proximity, the various graphs for the 2 years reveal that the capillary rise under the different moisture gradients was (a) extremely slow; (b) very small in total amount of
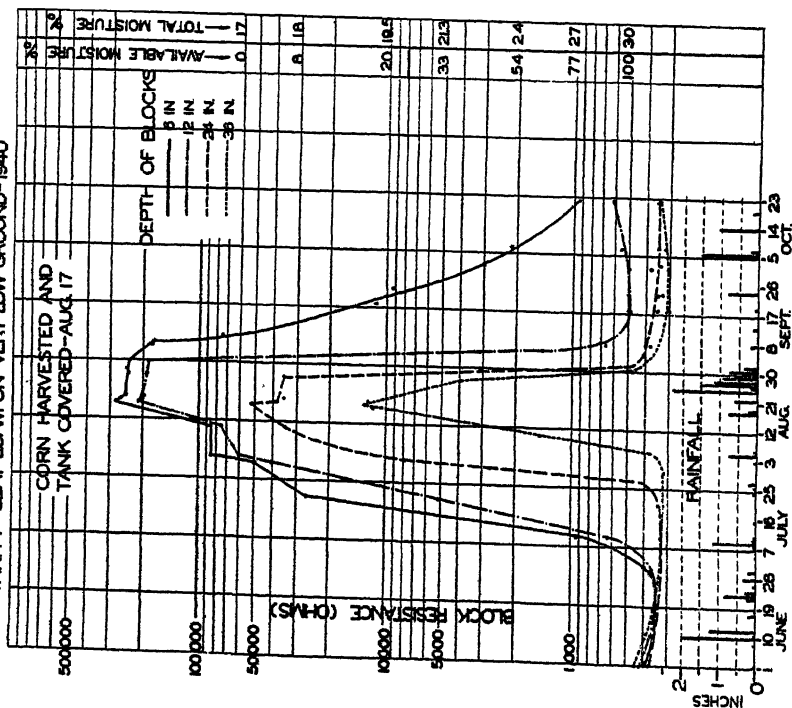
Fig. 1. Heavy Rainfall in August, which Raised the Water Table to the Surface, Wetted the Soil and Caused the Block Resistance to Fall Precipitously
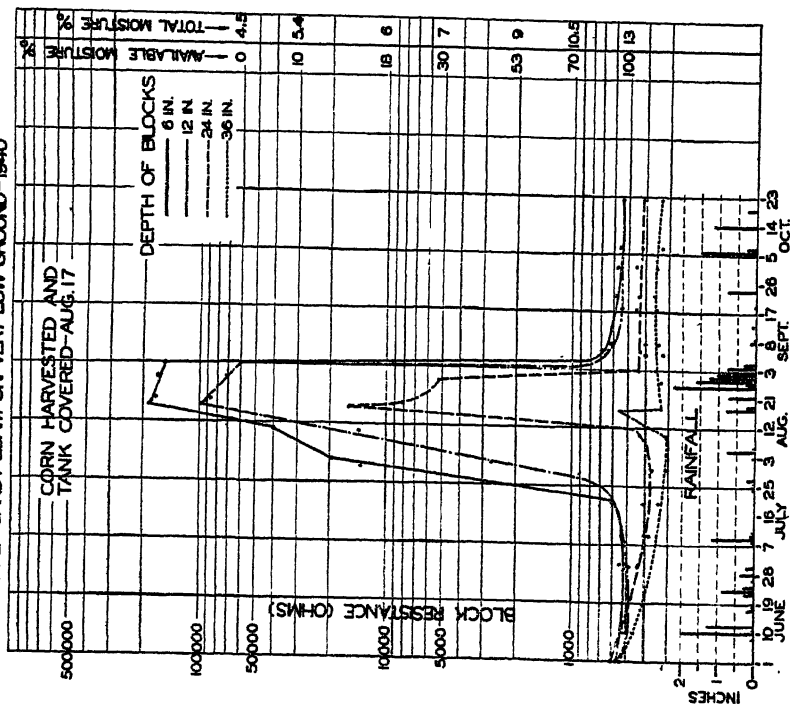


Fig. 2. Heavy Rainfall in August, Which Raised the Water Table to the Surface, Wetted the Soil and Caused the Block Resistance to Fall Precipitously
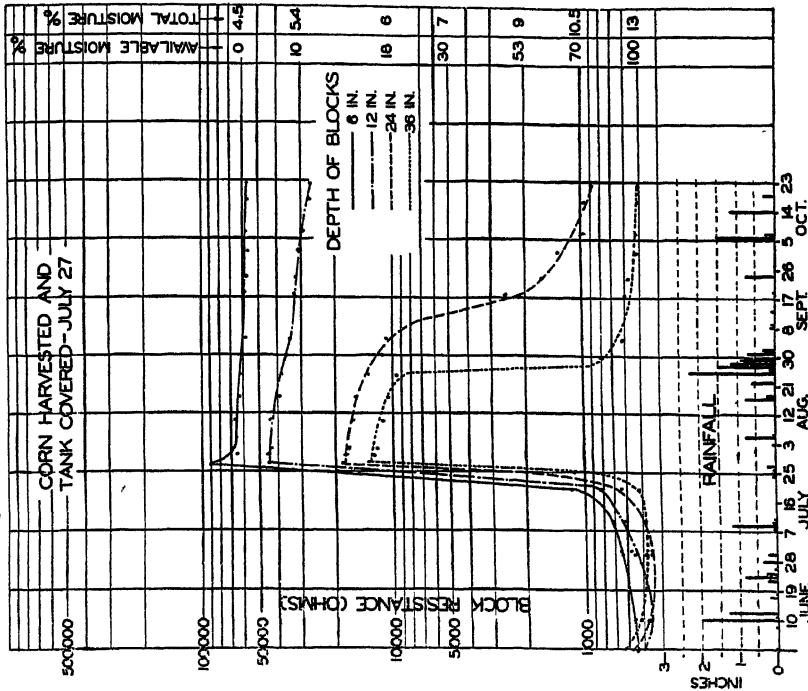
Fig. 4. On Medium-High Land and on Sandy Loam the Water Table Helped the Capillary Rise to Moisten the 36- and 24-Inch Depths but Had No Influence on the 6- and 12-Inch Depth in Approximately 2 Months Time
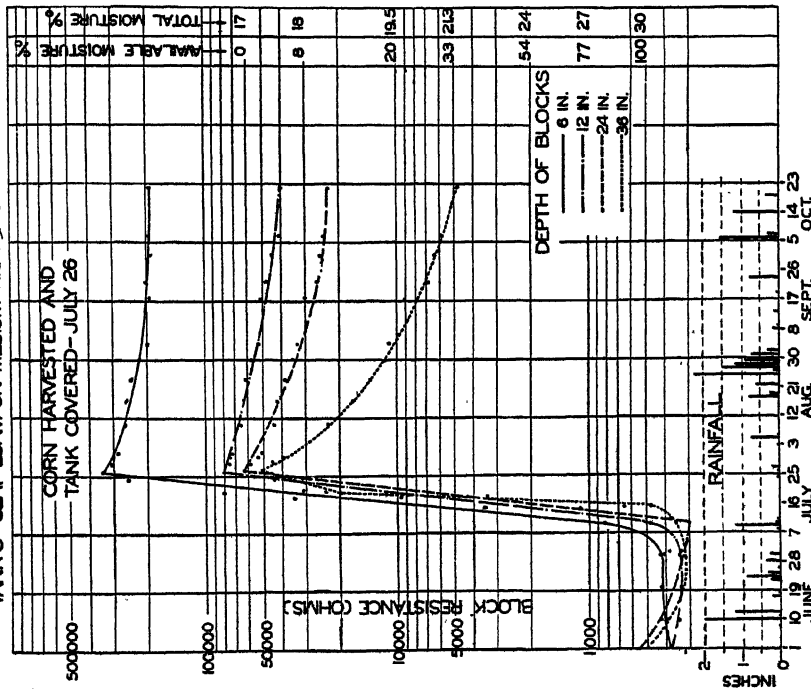
Fig. 3. On Medium-High Land and on Clay Loam There Was Virtually No Capillary Rise to the 6-, 12-, and 24-Inch Depths, and Only Slight Rise to the 36-Inch Depth

FIG. 5. ON HIGH LAND AND ON SILT LOAM THE HIGH WATER CONTENT AT THE 36-INCH DEPTH CAUSED LITTLE OR NO CAPILLARY RISE TO THE 6-, 12-, AND 24-INCH DEPTHS

FIG. 6. ON HIGH LAND AND ON SANDY LOAM THE CAPILLARY RISE HELPED TO WET THE 36-AND 24-INCH DEPTHS BUT HAD NO INFLUENCE ON THE 6- AND 12-INCH DEPTHS

FIG. 7. IN CLAY LOAM WHEN THE 24- AND 36-INCH DEPTHS WERE AT OR NEAR FIELD CAPACITY THE CAPILLARY RISE TO THE 6- AND 12-INCH DEPTHS WAS NEGLIGIBLE, IN SPITE OF THE VERY MARKED MOISTURE GRADIENT
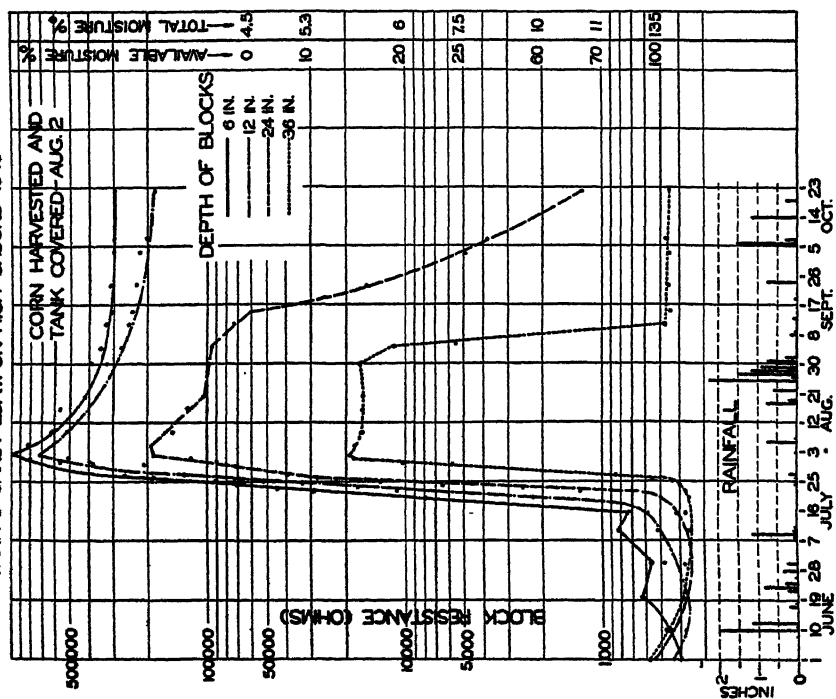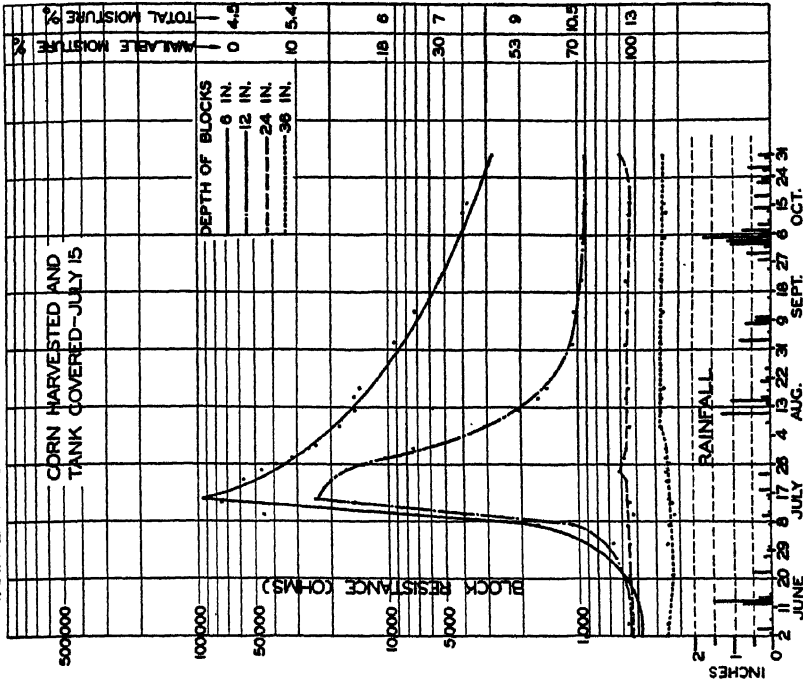
FIG. 8. IN SANDY LOAM WHEN THE 24- AND 36-INCH DEPTHS WERE MAINTAINED AT OR NEAR THE FIELD CAPACITY THERE WAS ENOUGH CAPILLARY RISE TO INCREASE THE AVAILABLE WATER IN THE 6-INCH DEPTH FROM THE NEIGHBORHOOD OF 0 TO ABOUT 50 PER CENT AND IN THE 12-INCH DEPTH, FROM 13 PER CENT TO ABOUT 75 PER CENT

Fig. 10. Even in Sandy Loam There Was Very Little Capillary Rise to the Upper Depths When the Water Table Was Far Down and the Moisture at the 36-Inch Depth Had Been Reduced to About 37 Per Cent of That Available



Fig. 9. On Clay Loam When the Water Table Was Far Down, and the Moisture Content at the 36-Inch Depth Was Reduced to About 23 Per Cent of Available Water, There Was Virtually No Capillary Rise to the 6- and 12-Inch Depths and Very Little to the 24- and 36-Inch Depths

FIG. 12. WHEN THE 6-, 12-, 24-, AND 36-INCH DEPTHS IN SANDY LOAM WERE REDUCED TO OR BEYOND THE WILTING POINT, THERE WAS VIRTUALLY NO CAPILLARY RISE TO THE UPPER THREE DEPTHS

FIG. 11. EXTREMELY NEGLIGIBLE CAPILLARY RISE IN CLAY LOAM EVEN WHEN THE 36-INCH DEPTH WAS AT FIELD CAPACITY AND THE MOISTURE GRADIENT TO THE 6-INCH DEPTH WAS VERY SHARP

moisture moved; (c) extremely limited in height. The magnitude of these capillary performances varied with the texture of the soil, being greater in sandy loam than in clay loam.

By referring to the block resistance and translating this into total moisture and available moisture content, one can readily see that the 6- and 12-inch depths in most tanks were reduced to or beyond the wilting point, and yet at the end of 2 or 3 months hardly any capillary moisture rose to increase the available moisture at these depths. This was especially true in the clay loam tanks. Even in the 24- and 36-inch depths, the capillary rise was relatively insignificant, provided the water table did not affect these depths either by upward force or by very close proximity.

4. In the graphs for 1940 and 1941, and also in data for three other years, there is conclusive evidence to the effect that the capillary rise was somewhat more active and of slightly greater magnitude in sandy loam than in clay loam, especially when the 24- and 36-inch depths remained at field capacity. This difference is most pronouncedly shown in clay loam tank 1 and in sandy loam tank 2 for 1941.

That the capillary rise in clay loam and even in silt loam was extremely slow was further attested by the following facts. After all the tanks were covered in July or August, 1940, they were kept covered until May, 1941. At the end of this 9- or 10-month period the 6- and 12-inch depths of clay loam on medium-high land and of silt loam on high land had not yet reached field capacity. For example, in the clay loam tank the 6-inch depth contained less than 20 per cent of available water and the 12-inch depth less than 50 per cent. In the silt loam tank, the 6-inch depth contained less than 60 per cent of available water and the 12-inch depth less than 80 per cent. (During the winter months the soils were frozen.) On the other hand, the capillary rise wetted all the sandy loam tanks to field capacity clear to the surface.

5. It will be noted in the graphs that when the crop was harvested and the tanks were covered, there was an immediate slight decline in the block resistance. This might be taken to mean that there was an immediate rise of capillary moisture. The possible explanation for the decline, however, would seem to be that, during the time the plants were growing, the roots were massed around the plaster of paris block and kept the block at high moisture tension. When the crop was harvested, the roots no longer exerted the pull for water on the block, the tension was released, and equilibrium was established between the block and the immediately surrounding soil.

6. This study has shown that the plaster of paris block electrical resistance method offers probably the most practical means ever used of studying the capillary rise of moisture in soils under field conditions. It gives a continuous and vivid picture of the moisture gradient at the various depths and of the capillary rise at the various moisture levels in the different textured soils, and classifies the soil moisture into total and available contents. The use of this method greatly helps to clarify, emphasize, and specify the actual role that capillary rise may play in the movement of moisture in the soil.

7. The results yielded by the method in this study lead to the general practical conclusion that capillary rise adds little if any moisture to the needs of the plants after the moisture falls below field capacity and a moisture gradient is established. At best, capillary rise is too slow and too small in amount to be of any significant help to plants in normal growing seasons.  This statement is self-evident when it is considered that the water requirements of the plants are immediate, large, and continuous, and that, according to this study, it took 3 months for the moisture in the 6- and 12-inch depths in some of the soils to increase from 8 per cent to 15 per cent of available water even though the 36-inch depth remained at field capacity.  Surely, such insignificant capillary rise is of negligible help to the growing plants.  The roots of the plants, therefore, have to go to where the water is.

## SUMMARY

The plaster of paris block electrical resistance method was applied to the study of the capillary rise of moisture in soils under field conditions.  This method has proved to be very practical for this study.

The main procedure followed was to grow plants in soil to reduce its moisture content to different values at various depths and thus create a moisture gradient, harvest the crop, cover the soil to prevent loss of moisture by evaporation, then study the movement of the soil moisture by means of the electrical resistance method.  The soil used was uniform in texture and was contained in tanks 3 by 3 feet without bottom and top but with watertight sides.  The tanks were sunk in field soils with shallow to very deep water tables.

The results yielded by this method showed that, where the water table did not rise to wet the soil by very close proximity, the actual capillary rise was extremely slow, very small in total amount of moisture moved, and extremely limited in height of movement.  The magnitude of these capillary movements varied with the texture of the soil, being somewhat greater in sandy loam than in clay loam.

The general practical conclusion drawn from this study is that capillary rise adds little, if any, moisture to the needs of the plants, during a short period, after the moisture falls below field capacity and a moisture gradient is established. This applies also to evaporation losses at the surface.

# BOOKS

*Animal Nutrition.* Second edition. By LEONARD A. MAYNARD. McGraw-Hill Book Company, Inc., New York, 1947. Pp. 467, figs. 44. Price $5.

Since a large number of agricultural experiment station workers are concerned with the problems of producing livestock or the crops that are to be fed to them or to man, a good book on animal nutrition is likely to be of considerable interest to many persons. This is such a book. In its revised form it gives the composition of the animal body, describes its life processes, follows the metabolism of the carbohydrates, lipids, and proteins, gives an excellent review of the available information on inorganic elements and their metabolism, and contains chapters on vitamins, feeding experiments, nutritional balances, measures of food energy, fasting, growth, reproduction, lactation, and work production. An extended bibliography of selected references is appended to each chapter. This is an important book that merits study.

*Concise Chemical and Technical Dictionary.* Edited by H. BENNETT. Chemical Publishing Company, Inc., Brooklyn, New York. Pp. 1055. Price $10.

This dictionary contains definitions of some 50,000 words and terms of interest to the chemist and engineer. Among them are thousands of trade names from the resin, plastic, metal, rubber, textile, food, pharmaceutical, paint, and varnish fields, including wetting and emulsifying agents, plasticizers, and detergents. Abbreviations are also shown, and a number of very useful tables are appended, including the Greek alphabet, Greek symbols, mathematical symbols, weights and measures, indicators, vitamin values, and important organic ring systems. The book should serve an exceptionally useful purpose to industrial chemists and will be very helpful in any research laboratory.

*Drought, Its Causes and Effects.* By IVAN RAY TANNEHILL. Princeton University Press, 1947. Pp. 264, figs. 118. Price $3.

This is a very attractively written book on a subject of great interest to all those dealing with crop production. The author analyzes the records in an attempt to determine the causes of droughts and whether they recur with any regularity. Among the several chapters are those dealing with deserts, famines, dusters, blizzards, sunspots, oceans, atmospheres, cycles, and the possibilities of a changing climate. The closing sentence is encouraging: "Droughts are not mere chance occurrences; they are part of a physical process which can be measured and studied and predicted with increasing precision as our observations of the sun and the upper air and the oceans continue to accumulate."

*The Land and Wildlife.* By EDWARD H. GRAHAM. Oxford University Press, New York, 1947. Pp. 232, plates 32. Price $4.

The writer of this book is concerned primarily with wildlife conservation on agricultural land. The areas under consideration are the marshes, ponds,

stream-banks, field borders, roadsides, windbreaks, hedges, gullies, cropped lands, pastures, forests, and ranges. The point is made that special efforts are required to protect birds, fish, and wild mammals against the encroachments of mankind and that only through education of the public as to the values of wildlife in the economy of Nature can we hope for such protection. The 32 full-page plates are exceptionally good examples of photographic recording of wildlife in its natural environment, with views of some of the domestic animals thrown in for good measure. A bibliography of about 150 references is appended.

THE EDITORS.

# CHEMICAL COMPOSITION OF SOME NATAL COASTAL DOLERITES AND THEIR ALTERATION PRODUCTS

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## OCCURRENCE OF DOLERITES ON THE NATAL COAST

A very extensive area of Southern Africa was at one time invaded by the basic magma of the dolerites.   This igneous rock, occurring most freely, though by no means exclusively, in the sedimentary formations, as sills and dikes, usually forms the caps and sides of small hills or ridges    Although the dolerites have erupted extensively and actively over periods of time, they have not produced any great metamorphic effects on the Karroo sediments through which they have largely passed.

Along the Natal Coast, the dolerites are nearly all confined to the Karroo sediments.   Kent[2], writing on the dolerites of a portion of Victoria County, has said:

Although all the pre-existing formations have been injected by Karroo dolerites in the form of sills and dykes, they are, however, practically confined to the Karroo sediments, only one small sheet-like body five feet thick being noted, for example, in the Old Granite. Even in the Karroo rocks the dolerites have, with the exception of a few thin sheets, practically avoided the unstratified Dwyka tillite.   In the stratified formations the most favoured horizons for dolerite injection were the base of stratified tillite passage beds, the junction of the Dwyka and the Ecca, the junction of the Lower and Middle Ecca, and the shale and sandy mudstone layers of the Middle Ecca, especially at or near their contacts with massive sandstone.   Practically all the dolerites were injected in the form of sills varying in size from mere stringers an inch or less in thickness, up to the large Verulam sill, which has a length of 10 miles, an outcrop width of from 0.1 to 0.5 miles, and a maximum thickness of 100 to 120 feet.

## DESCRIPTION OF DOLERITES

Dolerite is a dark bluish-gray crystalline rock.   In the center portions of the larger sills, the rock is of the coarse gabbroid variety, becoming fine-grained at the margins.   Petrologically, the dolerites are composed of labradorite, plagioclase, augite, magnetite, ilmenite, apatite, olivine, quartz, and some secondary pyrites, calcite, and chlorite.   Many of the dolerites are distinctly amygdaloidal in character.   The specific gravity varies between 2.95 and 3.05.

## CLIMATE OF NATAL COAST

The climate of the Natal Coast is subtropical with fairly prolonged dry periods during the winter.   The mean annual rainfall is slightly over 40 inches, the

[2] Kent, L. E.   The geology of a portion of Victoria County, Natal.   *Trans. Geol. Soc. So. Africa* 1938: 41, 1938.

majority of which falls in the warm summer months of November to March. The mean annual temperature along the coast is 68°F., ranging from a February mean of 75° to a July mean of 60°. The maximum monthly variation between the warmest and coolest months may amount to as much as 30°, though temperatures occasionally exceed 100° or fall to 35°.

The mean annual temperature of the earth at Mount Edgecombe, 10 miles north of Durban, is 71° at 1 foot (79° in February to 63° in July), 73° at 2 feet (80° in January to 65° in July), and 73° at 4 feet (79° in March to 67° in August). Maximum variations of 26°, 22°, and 17° have been noted at the 1-foot, 2-foot, and 4-foot levels respectively.

The normal annual relative humidity ranges from 74 per cent of saturation in the mornings to 63 per cent shortly after noon. Evaporation from a water surface exceeds annual rainfall by approximately 10 inches.

<div align="center">WEATHERING AND SOIL FORMATION</div>

Disintegration and decomposition of the dolerites proceed at a fairly rapid pace under favorable climatic conditions. The climate along the Natal Coast is not particularly favorable to rapid weathering. Despite this fact, and despite the effects of soil erosion, the parent dolerite is seldom found to any extent upon the surface, but usually is buried beneath a mantle of deep, rich soil.

In the region of Doornkop, at an altitude of some 1,900 feet, a moister climate is encountered, with frequent mists. Here the dolerites have weathered very rapidly under the influence of a continuous high moisture content. It is this high water content of the soil, decided chiefly by local topographical features and local geological boundaries, the latter influencing the distribution and flow of ground waters, that probably causes an observed variation in the weathering of dolerites along the Natal Coast.

The dolerites split along cleavage planes, possibly because of a strongly developed system of cross-jointing, and the resulting boulders weather spheroidally. In some instances, remnants of boulders unearthed in the soil profile display only in slight degree the characteristic spheroidal weathering. In such instances the soil is usually very damp and the weathered crust exceedingly soft and spongy. In other instances, particularly in situations where ground water does not seem so plentiful, the remnants of boulders retain concentrated layers of weathering material which can be successively removed by hand, the weathering material in such instances being an indiscriminate dirty gray, instead of the deep ocherous yellow of the former type of weathering.

The profiles of doleritic soils usually have the following structure and consistence: An inch or two of crumby, friable soil, followed by a foot or two of granular to crumby rather compact horizon, tending to become more compact and slightly cloddy with depth. Where weathering has proceeded apace, the soil remains granular and fairly friable for several feet, tending to become slightly compact and sticky with depth. In drier localities the soil becomes cloddy and compact for several feet, tending to become less compact in the vicinity of the weathering crust.

In texture, doleritic soils are usually heavy loams or clay loams, though occasionally a high percentage of fine sand may cause them to be classed as ordinary loams. The surface soils overlying dolerites may contain 30 per cent or more of coarse sand, a material which has undoubtedly been built up by secondary processes, as it is not produced with the weathering of dolerite. The subject of resilication will be discussed further on in this paper.

Secondary formations by way of either superficial ironstone or concretionary pebbles are infrequent, the former in fact never having been encountered by the writer on the Natal Coast. Concretionary pebbles, when they do occur, lie scattered throughout the profile and are not easy to detect in the field.

Not infrequently large quantities of limestone nodules, or concretionary limestone, have been found in doleritic soils. The occurrence of this material is not confined to any topographical situation, nor is it regularly dispersed. It is natural to suppose, however, that carbonate of lime would accumulate only under local conditions of slow ground water percolation.

The horizons of all doleritic soils are merging. The color of the soils is usually deep red, though black soils and intermediate chocolate-colored soils are common. In the red soils, the intensity of color usually increases with depth, assuming in some instances a yellowish tinge for about 12 inches, about 3 feet from the surface, before resuming its deep reddish color. In the intermediate horizons it is common to locate numerous rounded pellets of clayey material, which might be the completely weathered cores of fragmentary remains of the rock that has been split up along innumerable cleavage planes. These nodules were found to contain twice as much clay as the surrounding soil.

Immediately overlying the weathering crust specks of yellowish weathering rock occur in the soft ocherous type of weathering in relatively damp localities. In drier localities the transition from soil to weathering material is very sudden, the weathering material itself, however, often proceeding to a considerable depth before the original rock is encountered. In short, it would seem that under less favorable conditions of weathering the alteration products cannot be translocated by ground water to give rise to soil, though disintegration and decomposition might proceed, the products remaining *in situ*.

<div align="center">OBSERVATIONS ON SAMPLES SELECTED</div>

For chemical analyses, eight samples were taken at various points, representing both types of weathering. The stones with their weathering crusts were carefully removed from the profile, some of the soil immediately surrounding the weathered material also being taken.

The rock samples were then divided according to their weathering crusts. In the case of the soft ocherous weathering, the material was successively removed with a penknife, while in the other form of weathering the material was fairly readily peeled off by hand. In either case the sample representing the original rock was chipped from the core of the rock, well beyond the reach of weathering agencies. The air-dried samples were ground to a fine powder in an agate mortar, mixed, and set aside in stoppered bottles for chemical analyses. In the

case of the derived soils a mechanical analysis was made with some of the material before grinding. The results of the mechanical analysis indicate the texture of the derived soil, as distinct from the surface soil.

The first three samples were taken on the upper western extremity of the Doornkop Sugar Estates. Here at an altitude of 1,900 feet, the climate is somewhat cooler at night than at the actual seacoast, and frequent mists and a moderately high precipitation (50 to 55 inches per annum) keep the soil moist. The soils of this region normally retain as much as 30 or 40 per cent of moisture under field conditions, with a water-holding capacity of over 90 per cent. They are particularly high in organic matter. The samples were all removed from the lower depths of profiles exposed in test pits during soil survey operations.

The fourth sample was taken from a cutting at Frasers at an altitude of about 300 feet. In this locality the mean annual rainfall is 42 inches. The cool, misty conditions of the first three samples do not prevail.

TABLE 1

*Mechanical composition of soils immediately adjoining samples of weathering dolerite*

| TYPE OF WEATHERING | Soft ocherous (A) | | | Brittle grayish (B) | | |
|---|---|---|---|---|---|---|
| Sample number* | 3 | 4 | 5 | 6 | 7 | 8 |
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Coarse sand and gravel | 10.76 | 2.94 | 9.59 | 0.16 | 6.83 | 8.88 |
| (Gravel) | (1.41) | (0.21) | (2.55) | (0) | (0) | (0) |
| Fine sand | 26.49 | 9.31 | 13.47 | 7.64 | 27.39 | 17.76 |
| Silt | 15.57 | 11.08 | 33.83 | 23.92 | 17.66 | 16.77 |
| Clay | 47.18 | 76.67 | 43.11 | 68.28 | 48.12 | 56.59 |

* For the first two samples no derived soil was taken, but it may be assumed that the soil was very similar to that of the third sample, since samples 1, 2 and 3 were taken in the same area.

The sixth sample was again taken on the Doornkop Sugar Estates, but several miles nearer the coast than the previous samples, and out of the mist belt.

The fifth, seventh, and eight samples were taken from intrusions at Mount Edgecombe, where the mean annual rainfall is 37 inches. The climate at Mount Edgecombe differs appreciably from that at Doornkop, but it will be observed from a study of the analyses in table 1 that the type of weathering, whether A or B, cannot be accounted for alone by the prevailing climate. In other words, it would appear that *local conditions of ground-water movement* are more active in bringing about the different types of dolerite weathering discussed in this paper.

### CHEMICAL METHODS EMPLOYED

The usual technique of fusion with sodium carbonate in platinum crucibles was employed. Silica was obtained by dehydration. Oxide of iron was estimated from titrations with potassium permanganate, employing the Zimmermann-Reinhardt solution. Alumina was obtained by difference. Calcium and

magnesium oxides were obtained by the usual gravimetric methods, potash by the use of sodium cobaltinitrite, and sodium oxide by precipitation with zinc uranyl acetate, after fusion of a fresh sample by the well-known method of J. Lawrence Smith. Phosphoric, titanium, and manganese oxides were estimated colorimetrically. The pH value was measured with a glass electrode, the mixtures being allowed to stand 24 hours in stoppered bottles previous to measurement. Organic matter was determined by oxidation with sulfuric acid-dichromate mixture, excess being titrated with ferrous ammonium sulfate solution.

Quartz was not determined, nor was the amount of ferrous oxide. In dolerites, ferrous oxide may amount to as much as 8 per cent, thus quite appreciably affecting the summation. Attempts were made to estimate quartz by the use of Harrison's tri-acid mixture. The writer was unable to obtain reliable results, however, possibly because of some failure in interpretation of the technique, though the method was used successfully by Hardy and Follett-Smith[3].

### ANALYTICAL RESULTS

#### Type A weathering

The chemical analyses of samples 1 and 2 are shown in table 2, grouped together for convenience. In both cases the parent rock was medium- to coarse-grained and the weathering crusts were ocherous yellow and comparatively soft.

Most noticeable in the results shown in table 2 is the loss of silica as a result of weathering. Indeed, such desilication is the feature distinguishing the two types of weathering discussed in this paper. It will be seen that in type B weathering, no such loss of silica takes place.

Losses of calcium and magnesium are also considerable. On the basis of a formula[4] given by Merrill[5], the alumina remaining constant, the loss of calcium (CaO) is approximately 98 per cent, and that of magnesium (MgO) 99 per cent.

Such losses as these are remarkable in that they take place within a few millimeters of the unaltered rock, and are borne away through a weathering crust which may amount to as much as 3 cm. According to Harrison[6], the actual change from unaffected dolerite to the weathering product is a surface change occupying a maximum of about 1/6 inch. Hence, barely have the transition products of silica, calcium, magnesium, sodium, and, in some measure, potassium,

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[3] Hardy, F., and Follett-Smith, R. R. Studies in tropical soils: II. Some characteristic igneous rock profiles in British Guiana, South America. *Jour. Agr. Sci.* 21: 739–761, 1931.

[4] The formula is $\dfrac{100A}{B \times C} = x$, where $A$ = percentage of any constituent of the residual material; $B$ = percentage of same constituent in the fresh rock; and $C$ = the quotient obtained by dividing the percentage of alumina (or oxide of iron) of the residual material by that of the fresh rock.

[5] Merrill, G. P. A Treatise on Rocks, Rock Weathering, and Soils. Macmillan Co., London, New York, 1897.

[6] Harrison, J. B. The Katamorphism of Igneous Rocks Under Humid Tropical Conditions. Imperial Bureau of Soil Science, Harpenden, 1934

been formed, than they are removed. The small amounts remaining are probably occluded in the bulky weathering material, which is believed to consist largely of hydrous ferric oxide, aluminum trihydrate, and hydrated titania. It was observed that potassium is lost far less rapidly by this means than is sodium, no doubt because potassium silicates are more stable than sodium silicates.

In general, this type of weathering results in a loss of silica, the alkaline earths, the alkalies, and manganese, followed by a rapid fall in pH. As a result of such losses, the concentration of sesquioxides and titanium is raised, often being more than doubled. Many of the increases, such as that of phosphate, are apparent because of the loss of silica.

TABLE 2

*Chemical composition of dolerite and type A weathering crusts*

| | SAMPLE 1 (DOORNKOP) | | SAMPLE 2 (DOORNKOP) | | |
| --- | --- | --- | --- | --- | --- |
| | Original Rock | Total weathered crust | Original Rock | First Alteration | Second Alteration |
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$ | 52.40 | 11.28 | 47.96 | 15.69 | 18.28 |
| $Fe_2O_3$ | 14.66 | 27.50 | 17.65 | 31.70 | 45.65 |
| $Al_2O_3$ | 12.55 | 35.83 | 12.48 | 28.49 | 16.30 |
| $CaO$ | 10.65 | 0.44 | 10.14 | 0.59 | tr. |
| $MgO$ | 5.71 | 0.15 | 5.56 | 0.59 | 0.29 |
| $K_2O$ | 1.04 | 0.60 | 3.39 | 2.55 | 1.86 |
| $Na_2O$ | 2.39 | 0.14 | 2.39 | 0.50 | 0.17 |
| $P_2O_5$ | 0.15 | 0.20 | 0.33 | 0.39 | 0.36 |
| $TiO_2$ | 1.02 | 2.30 | 1.55 | 3.17 | 4.44 |
| $MnO$ | 0.21 | 0.05 | 0.23 | 0.15 | 0.05 |
| $H_2O$ | 0.63 | 21.74 | 0.45 | 17.60 | 13.67 |
| pH | 8.80 | 6.61 | ..... | ..... | ..... |

In succeeding samples, the subsoil immediately surrounding the weathered crust was also analyzed.

Table 3 illustrates the changes in chemical composition that take place from rock to soil. In this instance the weathering rock was an isolated stone about 1 foot in diameter, taken from a test pit at a depth of 46 inches. The unweathered core was medium-grained.

The fact which immediately emerges from the analysis in table 3 is that the silica lost in the weathering process is captured in formation of the soil, thus strengthening the conception that weathering and soil formation are distinct processes.

Research by Harrison on the katamorphism of dolerites in British Guiana, showed that the quartz and silica content of the derived soil is appreciably augmented, part of the silica set free assuming the form of quartz.

The writer has always observed that there is a considerable amount of sand in doleritic soil, whereas the type A weathering crust has a fine powdery texture.

Harrison concludes that this arenaceous material can have been produced only by the resilication of the primary laterite. The process of primary laterization

TABLE 3

*Chemical composition of dolerite, type A weathering crusts, and derived soil*
Sample 3 from Doornkop

| | ORIGINAL ROCK | FIRST ALTERATION | SECOND ALTERATION | DERIVED SOIL |
|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$................... | 52.47 | 22.54 | 14.53 | 39.63 |
| $Fe_2O_3$................... | 14.41 | 25.20 | 30.20 | 17.07 |
| $Al_2O_3$................... | 12.00 | 29.50 | 31.37 | 26.86 |
| CaO................... | 10.06 | 1.07 | 0.87 | 1.17 |
| MgO................... | 6.80 | 1.17 | 0.05 | 0.61 |
| $K_2O$................... | 1.20 | 1.14 | 0.97 | 0.63 |
| $Na_2O$................... | 2.66 | 0.75 | 0.08 | 0.16 |
| $P_2O_5$................... | 0.17 | 0.27 | 0.23 | 0.11 |
| $TiO_2$................... | 1.86 | 2.48 | 2.43 | 1.18 |
| MnO................... | 0.07 | 0.07 | 0.06 | 0.16 |
| $H_2O$................... | 0.68 | 16.23 | 19.31 | 14.66* |
| pH................... | 8.00 | 6.40 | 5.70 | 5.70 |

' Containing 0.86 per cent organic matter.

TABLE 4

*Chemical composition of dolerite, type A weathering crusts, and derived soil*
Sample 4 from Frasers

| | ORIGINAL ROCK | FIRST ALTERATION | SECOND ALTERATION | DERIVED SOIL |
|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$................... | 49.76 | 15.87 | 14.41 | 41.86 |
| $Fe_2O_3$................... | 17.41 | 32.69 | 37.78 | 20.51 |
| $Al_2O_3$................... | 13.19 | 25.62 | 23.75 | 22.20 |
| CaO................... | 10.41 | 1.02 | Traces | Traces |
| MgO................... | 6.06 | 0.86 | 0.41 | 0.47 |
| $K_2O$................... | 1.19 | 1.78 | 2.30 | 1.13 |
| $Na_2O$................... | 2.02 | 0.47 | 0.19 | 0.20 |
| $P_2O_5$................... | 0.19 | 0.29 | 0.27 | 0.14 |
| $TiO_2$................... | 1.53 | 3.87 | 4.62 | 2.23 |
| MnO................... | 0.32 | 0.15 | 0.24 | 0.15 |
| $H_2O$................... | 0.10 | 17.57 | 17.21 | 12.05* |
| pH................... | 7.20 | 5.43 | 5.18 | 5.38 |

* Containing 1.66 per cent organic matter.

is succeeded by one of resilication, wherein the silica of the ground water is reabsorbed into the soil. Table 1 shows that in several of the samples the coarse and fine sands amount to 20 to 30 per cent of the soil.

The accumulation of calcium and magnesium in the soil is very slight. Nor do these elements come to the surface with capillary rise of water; the red doleritic soils are somewhat deficient in calcium and magnesium, particularly in the case of type A weathering.

Silica appears to be localized in many of the weathering crusts. This results in the ocherous mass becoming speckled white, more noticeably in the first zone of alteration than elsewhere.

The fourth sample examined (table 4) was a small stone a few inches in diameter, the isolated core of a large dolerite boulder. Despite the smallness of the stone, the parent rock possessed a core that was still quite unaffected by weathering agencies. The rock was very fine-grained.

TABLE 5

*Chemical composition of dolerite, type A weathering crusts, and derived soil*

Sample 5 from Mount Edgecombe

|  | ORIGINAL ROCK | FIRST ALTERATION | SECOND ALTERATION | DERIVED SOIL |
|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$............... | 52.05 | 17.69 | 17.20 | 47.82 |
| $Fe_2O_3$............... | 16.04 | 28.61 | 44.77 | 20.39 |
| $Al_2O_3$............... | 11.19 | 32.15 | 17.12 | 12.56 |
| CaO............... | 10.83 | 0.61 | 0.49 | 1.20 |
| MgO............... | 6.06 | 0.53 | 0.62 | 0.31 |
| $K_2O$............... | 1.62 | 0.95 | 1.03 | 1.70 |
| $Na_2O$............... | 2.22 | 0.22 | 0.22 | 0.28 |
| $P_2O_5$............... | 0.21 | 0.23 | 0.18 | 0.12 |
| $TiO_2$............... | 1.16 | 2.72 | 3.24 | 1.92 |
| MnO............... | 0.24 | 0.18 | 0.11 | 0.11 |
| $H_2O$............... | 0.45 | 18.36 | 15.93 | 14.72* |
| pH............... | 8.00 | (7.10) | (7.00) | (6.95) |

* Containing 3.96 per cent of organic matter.

In this sample, resilication has again occurred, all other alterations also being of the same order as the previous sample. The rock is, however, less basic than usual, though the fall in pH between the rock and the first zone of alteration is considerable.

The next analysis (table 5) is the final example of type A weathering. The subsoil in the area of this sample is filled with a large number of small doleritic stones, mostly with unweathered cores. An interesting feature about type A weathering is the manner in which the core of dolerite is protected by the weathering coat. Such protection is not afforded by type B weathering, which generally proceeds in some small measure to a fair depth. Small stones of type B weathering are, nevertheless, frequently found in which the core is unaffected.

The dolerite of the sample analyzed in table 5 was fine-grained. The sample was taken at a depth of approximately 40 inches from the surface.

This sample again illustrates the surprisingly constant nature of the resilica-

tion in type A weathering. In the third sample there was 2.7 times the amount of silica in the soil as in the outer weathered crust; in the fourth 2.9 times, and in the fifth 2.8 times the amount. In each of the three examples, oxide of iron ($Fe_2O_3$) and titanium oxide ($TiO_2$), on the other hand, have decreased in the derived soil by almost exactly half the amount in the outer weathered crust.

The alkaline nature of the crust is undoubtedly explained by the fact that the field has been treated regularly with strongly alkaline sugar factory filter cakes, a by-product rich in lime. For this reason, the results obtained are shown in parentheses in table 5.

TABLE 6

*Chemical composition of dolerite, type B weathering crusts, and derived soil*
Sample 6 from Doornkop

|  | ORIGINAL ROCK | FIRST ALTERATION | SECOND ALTERATION | DERIVED SOIL |
|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$ | 51.02 | 51.21 | 48.86 | 39.69 |
| $Fe_2O_3$ | 16.71 | 16.06 | 16.29 | 19.63 |
| $Al_2O_3$ | 10.34 | 11.27 | 13.62 | 23.01 |
| CaO | 11.07 | 10.29 | 8.56 | 0.41 |
| MgO | 7.11 | 6.99 | 6.24 | 0.74 |
| $K_2O$ | 1.66 | 1.69 | 1.10 | 0.49 |
| $Na_2O$ | 2.26 | 1.81 | 1.82 | 0.21 |
| $P_2O_5$ | 0.20 | 0.21 | 0.17 | 0.11 |
| $TiO_2$ | 1.08 | 1.19 | 1.32 | 1.29 |
| MnO | 0.43 | 0.36 | 0.36 | 0.17 |
| $H_2O$ | 0.87 | 1.29 | 3.52 | 12.83* |
| pH | 8.18 | 7.40 | 6.51 | 5.88 |

* Containing 0.98 per cent of organic matter.

### Type B weathering

The first of the samples of type B weathering, taken at the Doornkop Sugar Estates, at an altitude of about 1,500 feet, represents a fine-grained dolerite. As pointed out earlier, the crusts of type B weathering are well-defined, brittle, and an indiscriminate grayish to greenish gray, often assuming a grayish yellow in the outer crust. The crusts analyzed in table 6 were mottled on their surfaces with frequent dark patches of secondary iron or manganese.

Scarcely any desilication has taken place in the weathering process, and a further moderate loss has taken place in the final transition to soil. Of particular interest in this type of weathering is the retention of the alkaline earths and alkalies in the weathering crusts, followed by the sudden removal of these substances in the derived soil. The protective influences would appear to be suddenly overcome and the components of the outer weathering crusts carried away. In type A weathering, the components were not protected by the weathering crusts, being carried away directly from the weathering surfaces of

the rock. Favorable ground-water conditions are said to be the reason for this latter more spectacular form of weathering.

Sample 7, shown in table 7, was taken at Mount Edgecombe, about 1 mile east of sample 5, in the same intrusion. The writer was unable to obtain a sample of the rock quite unaffected by weathering agencies. The core of the stone selected for analysis was at first believed to be unaffected, but closer examination, supported by chemical analysis, revealed that alteration had already taken place, though the material was so hard that it could be broken only with a hammer.

It is of interest to observe how little of the lime has been removed in the successive coats of weathering. The unduly high silica content and low calcium

TABLE 7

*Chemical composition of weathering doleritic core—type B, crusts, and derived soil*

Sample 7 from Mount Edgecombe

|  | SLIGHTLY WEATHERED CORE | FIRST ALTERATION | SECOND ALTERATION | DERIVED SOIL |
|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$.................... | 60.94 | 60.19 | 58.10 | 48.11 |
| $Fe_2O_3$.................... | 7.82 | 8.33 | 12.11 | 14.27 |
| $Al_2O_3$.................... | 17.89 | 17.11 | 15.31 | 19.28 |
| CaO.................... | 5.14 | 4.96 | 4.97 | 1.95 |
| MgO.................... | 0.94 | 1.58 | 2.46 | 1.38 |
| $K_2O$.................... | 1.77 | 1.56 | 1.60 | 1.30 |
| $Na_2O$.................... | 1.93 | 1.74 | 1.36 | 0.69 |
| $P_2O_5$.................... | 0.14 | 0.13 | 0.14 | 0.12 |
| $TiO_2$.................... | 1.70 | 1.95 | 1.88 | 1.48 |
| MnO.................... | 0.13 | 0.13 | 0.12 | 0.32 |
| $H_2O$.................... | 4.00 | 3.95 | 4.28 | 12.85* |
| pH.................... | 7.78 | (8.10) | (7.75) | (7.34) |

* Containing 3.00 per cent organic matter.

and magnesium contents, even for the first weathered products, suggest to the writer that this rock sample may not be a truly representative dolerite even though it was strikingly typified by spheroidal weathering. The surrounding Ecca shale occurs a few dozen yards away, and it may be that the rock has been slightly affected petrographically by the sedimentary formation through which it passed.

In all respects the product appears to be quite similar to other samples of type B weathering and will pass muster for the purposes of this paper. The pH values in table 7 enclosed in parentheses, are as it is again suspected that the application of filter cake in this locality may have influenced the results.

Sample 8 was taken about 1 mile south of the previous sample and from an adjoining intrusive area. The rock was again fine-grained, and the zones of alteration were similar in most respects to those described previously for this type of weathering. The weathering stone was removed from a quarry, where

the soil was filled with numerous other stones of all sizes, all embedded separately in the matrix of blackish soil. It may be mentioned here that, with the exception of sample 8 and of the chocolate-colored sample 7, all the samples of derived soil were of a deep reddish color.

As shown in table 8, silica is again retained throughout, but little of the alkaline earths being lost in the first two layers of weathering material. In the third or outer zone of alteration, which was light yellowish and still moderately brittle, the alkaline earths diminished appreciably. The accumulation of some potassium in the soil is not usual. Neither is the high organic matter content

TABLE 8

*Chemical composition of dolerite, type B weathering crusts and derived soil*

Sample 8 from Mount Edgecombe

|  | ORIGINAL ROCK | FIRST ALTERA-TION | SECOND ALTERA-TION | THIRD ALTERA-TION | DERIVED SOIL |
|---|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| $SiO_2$ | 52.41 | 53.24 | 51.98 | 46.09 | 50.94 |
| $Fe_2O_3$ | 12.28 | 9.99 | 13.17 | 14.00 | 11.20 |
| $Al_2O_3$ | 15.15 | 16.49 | 16.49 | 21.57 | 15.34 |
| $CaO$ | 9.70 | 8.67 | 7.38 | 4.54 | 1.92 |
| $MgO$ | 7.26 | 6.64 | 5.54 | 3.83 | 1.05 |
| $K_2O$ | 1.16 | 1.47 | 1.26 | 1.78 | 2.34 |
| $Na_2O$ | 2.10 | 1.71 | 1.88 | 1.47 | 0.27 |
| $P_2O_5$ | 0.19 | 0.20 | 0.19 | 0.19 | 0.14 |
| $TiO_2$ | 1.06 | 1.05 | 1.05 | 1.26 | 1.18 |
| $MnO$ | 0.28 | 0.23 | 0.23 | 0.27 | 0.13 |
| $H_2O$ | 0.90 | 1.85 | 3.27 | 7.62 | 16.46* |
| pH | 8.40 | 7.35 | 7.10 | 6.81 | 6.16 |

* Containing 6.34 per cent organic matter.

at the depth of sampling, about 28 inches from the surface, though of course the extreme blackness of the soil would point to high organic matter.

Type B weathering is characterized by "reshuffling" of chemical components in the crusts, as opposed to "transportation" in type A weathering. The final processes of soil formation are likewise different, the secondary reaction of resilication being a dominant factor in the formation of soils overlying dolerite of type A weathering.

SUMMARY

Some observations are made on dolerites in general as they occur on the Natal Coast.

A brief description of the climate of the Natal Coast is given, together with remarks on weathering and soil formation. It is suggested that differential weathering of dolerites is accounted for by local variations in gravitational, capillary, and pellicular water.

The chemical analyses of five samples depicting type A weathering (soft ocherous crust) and three samples depicting type B weathering (brittle grayish crust) are given.

The results of the analysis indicate that in type A weathering there has been, among other points of interest, a great loss of silica, alkaline earths, and sodium oxide. In type B weathering, these materials have been only slightly removed from the weathering crust.

In type A weathering the secondary process of resilication has proceeded actively, resulting in a very sharp increase of silica in the derived soil.

As these distinct types of weathering were found to occur in the same localities and in dolerite of similar composition, it is maintained that, in the instances referred to in this paper, climate has had a less important role in weathering and soil formation than have purely local conditions of ground water.

# A SIMPLE METHOD OF ISOLATING BACTERIA-FREE CULTURES OF PROTOZOA

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Numerically, protozoa form the most abundant group of the animal population in soil, but very little is known of their actual role in various soil processes. The protozoan theory of Russell and Hutchinson (7) on the partial sterilization of soil, followed by Nasir's (4) work on increased nitrogen fixation with the association of protozoa, stimulated considerable interest in this group of organisms. Very little work on the subject has been done during the last 24 years, however, chiefly because of the difficulty of isolating bacteria-free cultures of protozoa. Many attempts have been made in this direction, but the methods evolved are so laborious and uncertain that no significant success has been achieved so far.

Gordon (2) described a method for isolating amoeba in which use was made of the fact that protozoan cysts are more resistant than bacteria to 2 per cent HCl. Use of the Barber pipette or Chamber's apparatus has also been suggested. Peters (5) succeeded in isolating a pure culture of *Colpidium colpoda* by the drop method, but his culture was subsequently found to be contaminated with bacteria. An electrolytic method was suggested by Amster (1), who found that under the influence of a fall in potential the protozoa travel to the cathode and the bacteria to the anode.

Most of the methods enumerated have been tried many times in this laboratory, but with little success.

After repeated trials, a new and a much simpler method has been evolved, which with a little practice can be expected to give very good results. The method is based on the principle that protozoa travel at a much greater speed than bacteria.

## TECHNIQUE OF METHOD

### Preparation of tubes

Glass tubing of approximately 3-mm. bore is thoroughly cleaned, and a few capillary tubes shaped like that shown in figure 1 are prepared from it. Each tube is about 20 cm. long.

End *A* is drawn out and sealed. The tube is heated slightly in the zone of greatest width to expel part of the air and is sealed at *B*. The tubes are then sterilized in the hot-air oven. If desired, a cotton wool plug may be inserted near end *B* before sealing and prior to sterilization.

### Filling and use of capillaries

To fill the tubes with the medium, end *A* is heated to redness in a flame and immediately immersed in sterile culture medium contained in a culture tube.

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The hot end cracks off, and the medium rushes in. The following media were used in the present study:

Horse dung extract medium, as described by Martin and Lewin (3, p. 113), which had been passed through filter paper.
Beef extract medium containing 0.5 gm. each of beef extract and sodium chloride in 1,000 cc. water.

After the tube has assumed room temperature it is cut at $C$ and fixed on the mechanical stage of the microscope with a little plasticine or other adhesive. The tube is then inoculated with a loopful of the fresh impure culture of the protozoa and their movement followed under the low power. The leading organism is kept under observation and when it has travelled about 7 cm. away



Fig. 1. Capillary Tube for Isolating Motile Culture of Protozoa

from the seat of inoculation, $C$, the capillary is hurriedly broken off near this point and carefully sealed in the flame. The tube is reexamined to make sure that the organism is encaged and then is incubated at optimum temperature, which ranges between 20 and 25° C. for most of the ciliates and flagellates.

After about 3 days' incubation, when the tube is reexamined under the microscope, it is often (in about 40 per cent of the cases) found to be full of the progeny of the single cell.

### EXPERIMENTAL OBSERVATIONS

It generally takes 15 to 30 minutes to capture an organism. In practice it was found that in running through about 7 cm. of the capillary space, the organisms rid themselves of attached bacteria. Smears prepared from such tubes have seldom shown the presence of any bacteria, but reinoculations from these capillary tubes on ordinary culture tubes have failed to grow the protozoa. Experiments are in progress to find out the causes of this failure in subculturing.

The following observations were made during the trials:

If the tubes prepared for the study are first filled with medium and then sterilized, the protozoa when inoculated become sluggish and very often fail to disperse into the capillary. This is apparently due to deficiency of dissolved oxygen in the medium. For this reason, therefore, freshly sterilized culture media should not be used for filling the capillaries.

If the capillaries are filled with distilled water, the protozoa travel much faster, often reaching the other end in about 5 minutes. This is apparently due to the low viscosity of distilled water as compared with that of the medium. The use of a diluted medium, therefore, is advantageous.

Sometimes the protozoa do not disperse into the medium, but keep moving about the organic matter that has been carried with the inoculum. A droplet of starch solution introduced at this end serves to dislodge the protozoa, apparently because of increased viscosity.

Air bubbles in the filled capillaries are undesirable, as they obstruct the passage of the organisms.

Protozoa usually move in the capillary tubes in a zigzag manner. Hence, very narrow capillaries should be avoided.

Isolations should not be done when the room temperature is falling, otherwise the impure culture may be sucked into the capillary.

### DISCUSSION

The method is applicable only to actively motile cultures of protozoa and is based on the assumption that protozoa move much faster than bacteria. Thus there is greater likelihood of protozoa reaching the other end of the capillary much sooner than bacteria. During passage of the protozoa along about 7 cm. of the capillary, the adhering organisms are washed off.

As has been mentioned, in about 60 per cent of the cases the encaged organism failed to multiply. This may be due to the absence of the bacterial food which some of them specifically require, or it may be due to the absence of the "alle-locatalytic effect" described by Robertson (6).

Failure of protozoa to grow when inoculated into ordinary culture tubes is not unusual. It was recorded by Robertson, who attributed it to the amount of medium to which a transfer is made; by Peters in cultivation of *Colpidium colpoda;* and by Pasteur and others in cultivation of yeasts. Possibly some necessary substance is dissipated by the protozoa cells into the surrounding medium and the rate of reproduction is proportional to the concentration of the substance. When the substance is too dilute or is dissipated into too large a volume of medium, reproduction and even maintenance become impossible. Further experiments are in progress to throw light on this theory.

The method has been found successful for isolating a protozoan cell from bacteria, but it needs trial in different hands. Before it can be of practical use, the difficulty in subculturing must be surmounted. Meanwhile, the method is offered to stimulate interest and to induce suggestions and comments.

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# ANALYSES OF VEGETABLE FERTILIZER PLOTS WITH A SOIL TEST WHICH MEASURES ACID-SOLUBLE AND ADSORBED PHOSPHORUS[1]

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Received for publication July 12, 1946

Considerable evidence has been presented which indicates that, in addition to the acid-soluble forms of phosphorus that have long been considered effective in plant growth, significant amounts of phosphorus may be adsorbed by the soil in an anion-exchange complex (2, 15, 16, 17, 18, 19, 21) and that phosphorus thus held may be utilized by certain crops (4, 8, 20). Bray and his associates[3] (4, 5) have developed soil tests which fractionate the available phosphorus into these two forms. These tests have been useful in studying such problems as the manner in which applied phosphorus fertilizers are retained by the soil (4, 13). Also the test for total available phosphorus, which includes both forms, has been found to give more reliable estimates of phosphorus fertility levels over a wide range of conditions than was possible with tests that measured primarily acid-soluble forms (4, 6). Most of the work done with these tests has been on soil in field crop production in which relatively light applications of fertilizers have been made. This paper presents the results of analyses made on soil samples taken from three vegetable fertilizer experimental plots in which different amounts and kinds of phosphorus fertilizers have been applied for ten or more years, and in which the rates of application far exceed those found in field crop experiments. The objective was to see how well the results of the analyses could be correlated with these treatments and with crop response.

## METHODS

### Extraction system

The extraction system used is outlined in table 1. In addition to the PA2 and PA1 extracting solutions used by Bray, a PA0 extracting solution has been included in which the 0.025 $N$ HCl is buffered to the same pH as the PA1 solution with ammonium acetate instead of ammonium fluoride. The acetate ion has been shown by Kurtz (13) to be ineffective in replacing adsorbed phosphorus. Use of this extracting solution thereby makes it possible to delineate more clearly the portion that could be attributed to the action of the fluoride ion. Bray[3] has pointed out the necessity of using 0.025 $N$ HCl with ammonium fluoride in the

quick test technique in order to overcome the effect of calcium and magnesium which tend to retard the removal of adsorbed forms by the fluoride (11). The portion removed by the PA0 solution might be considered as a weak acid-soluble

### TABLE 1

*Type of extractions made and calculations used to determine relative amounts of different available forms of phosphorus*

| EXTRACTING SOLUTION | NATURE OF THE EXTRACTING SOLUTION | pH | FORMS EXTRACTED | | |
|---|---|---|---|---|---|
| PA2 | 0.1 $N$ HCl<br>0.03 $N$ NH₄F | 1.8 | Acid-soluble | Adsorbed | Flush |
| PA1 | 0.025 $N$ HCl<br>0.03 $N$ NH₄F | 3.0 | | Adsorbed | Flush |
| PA0 | 0.025 $N$ HCl<br>0.024 $N$ NH₄C₂H₃O₂ | 3.0 | | | Flush |

Calculations

| PA1-PA0<br>PA2-PA1 | | | Acid-soluble | Adsorbed | |
|---|---|---|---|---|---|



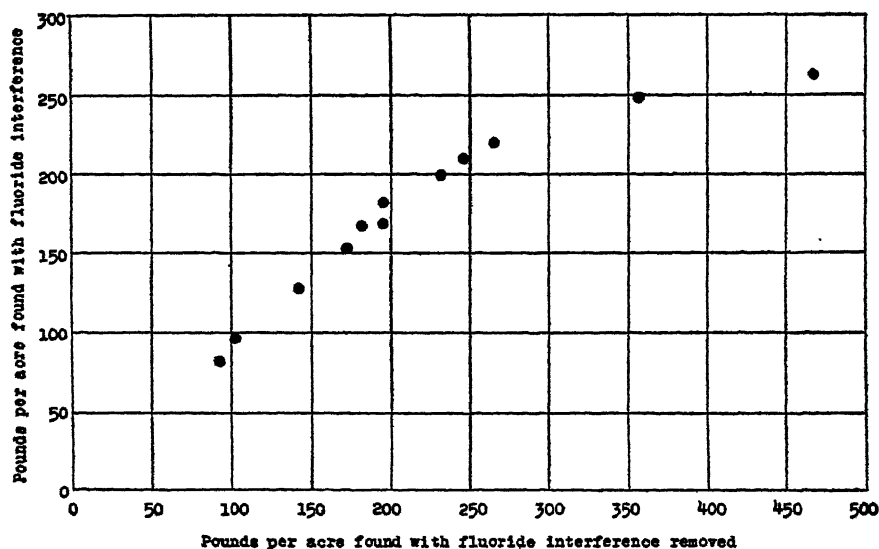FIG. 1. EFFECT OF FLUORIDE INTERFERENCE ON DEVELOPMENT OF MOLYBDENUM BLUE COLOR AS ILLUSTRATED BY ANALYSES OF THE MARIETTA PLOTS

fraction. Since the most easily available adsorbed forms can be extracted with distilled water, however, it is more likely that the easily available portions of both acid-soluble and adsorbed phosphorus are removed with this solution. For this reason it is called the "flush" fraction.

*Fluoride interference*

Bray indicated in his description of the quick test method that the fluoride concentration on the PA2 and PA1 extractants was not high enough to cause interference with the color development. In work with the higher concentrations of phosphorus obtained in extracts from soils in vegetable production, it became apparent, however, that such interference was taking place. This is illustrated in figure 1. It will be noted that the depression of the color development becomes greater as the phosphorus concentration in the extract increases. This tends to decrease the apparent difference between the PA2 and the PA1 tests and thereby gives an erroneous estimate of the acid-soluble fractions. The lack of fluoride interference tends to give the PA0 test a relatively higher rating. As a consequence, all extracts were treated with boric acid as suggested by Kurtz (12) for the removal of fluoride interference. Subsequent to the completion of these analyses it was found that the fluoride interference could be removed more conveniently by saturating the ammonium molybdate reagent with boric acid[4].

*Phosphorus determinations*

*Reagents*

1. Ammonium fluoride stock solution (approximately $2 N$ $NH_4F$). Dissolve 37 gm. $NH_4F$ in distilled water and dilute to 500 ml. Keep in a paraffined bottle.
2. Hydrochloric acid stock solution (approximately $0.5 N$ HCl). Dilute 20.2 ml. of concentrated HCl to 500 ml. with distilled water.
3. Ammonium acetate stock solution (approximately $2 N$ $NH_4C_2H_3O_2$). Dissolve 77 gm. $NH_4C_2H_3O_2$ in distilled water and dilute to 500 ml.
4. Acid ammonium molybdate stock solution. Dissolve 100 gm. of c.p. ammonium molybdate in 850 ml. of distilled water. Filter and cool. Make a second solution of 1,700 ml. of concentrated hydrochloric acid (36 per cent) mixed with 160 ml. of distilled water. Cool. Add the first solution to the second solution slowly and with constant stirring. This reagent will keep 3 to 4 years.
5. Amino-napthol-sulfonic acid reagent. Mix 2.5 gm. of 1-amino 2-napthol 4-sulfonic acid, 5.0 gm. sodium sulfite, ($Na_2SO_3$), and 146.25 gm. of sodium bisulfite (meta $Na_2S_2O_5$) in a mortar and grind to a fine powder. Dissolve 8 gm. of this mixture in 50 ml. of warm distilled water. This reagent will remain effective for two or more weeks.
6. PA2 extracting solution. Add 200 ml. of $0.5 N$ HCl and 15 ml. of $2 N$ $NH_4F$ to a 1,000-ml. volumetric flask and dilute to the mark with distilled water.
7. PA1 extracting solution. Add 50 ml. of $0.5 N$ HCl and 15 ml. of $2 N$ $NH_4F$ to a 1,000-ml. volumetric flask and dilute to the mark with distilled water.
8. PA0 extracting solution. Add 50 ml. of $0.5 N$ HCl and 12 ml. of $2 N$ $NH_4C_2H_3O_2$ to a 1,000-ml. volumetric flask and dilute to the mark with distilled water.
9. Boric acid solution ($0.8 M$ $H_3BO_3$). Dissolve 49.4 gm. of boric acid in distilled water and dilute to 1,000 ml.

*Technique*

Air-dried soil passed through a 1-mm. screen was used in all determinations. Into a 50-ml. Erlenmeyer flask, 1.5 gm. of soil was weighed, 15 ml. of extracting solution added, and the mixture shaken for 1 minute. The flask was then laid

[4] Arnold, C. Y., and Kurtz, T. 1946 Photometer method for determining available phosphorus in soils. Ill. Agr. Exp. Sta. Mimeo. Leaflet AG1306.

in a tilted position for another minute to allow the bulk of the soil to settle. The fluid portion was poured off and filtered through a number 2 Whatman filter with paraffined edges. An aliquot of the extract and 7.5 ml. of 0.8 $M$ boric acid were added to a 25-ml. volumetric flask and made up to the mark with distilled water (12). To 5 ml. of the treated extract were added 0.2 ml. of acid ammonium molybdate and 0.2 ml. of amino-napthol-sulfonic acid solution. Color intensity was read 15 to 20 minutes later in a Cenco-Sheard-Sanford photolometer, model $C_3$, using a green filter ($530\mu$). Concentrations were determined from a curve made under similar conditions with standard phosphorus solutions.

<div align="center">FERTILIZER PLOTS</div>

The first of the fields from which samples were taken is at the Washington County Truck Crops Experiment Farm near Marietta, Ohio. The phosphorus series of this experiment had been receiving different amounts of phosphorus fertilizers for 24 years at the time of the last sampling in 1938. The soil is Chenango fine sandy loam to loam.

The second set of samples came from the phosphorus series of the vegetable fertilizer plots at Ohio State University, Columbus. These plots were established in 1930. The samples were obtained in the winter of 1945. The soil is Brookston silt loam.

The third group was taken from the fourth and fifth replications of the phosphorus plots at the Cook County Experiment Station near Des Plaines, Illinois. These plots had been in existence 10 years when they were sampled in 1943. The soil varies from Lisbon silt loam to clay loam and silty clay loam.

<div align="center">DISCUSSION</div>

<div align="center">*Marietta plots*</div>

The total available phosphorus as measured by the PA2 extractions on the Marietta plots shows a good correlation with the phosphorus fertilizer treatments (table 2). It should be pointed out that the total amount removed by the extraction method described here is only about one half that which can be removed with a wider soil extract ratio and longer shaking, as described by Bray and Kurtz (5). If approximate comparisons are to be made between changes in the soil test and amount of phosphorus fertilizer applied, the soil test value should be multiplied by 4 to take this into consideration and also to account for the conversion from P to $P_2O_5$. Thus, the 145-pound increase in the soil test of plot 32 between 1931 and 1938 represents about 580 pounds of $P_2O_5$, which is about 60 per cent of the 960 pounds applied in the fertilizer. The increase in the test on plot 34 represents about 50 per cent of the phosphorus applied. This accounts for a much larger proportion of the phosphorus applied than would be expected on the basis of statements made about phosphorus fixation in the literature.

Many workers (1, 3, 15, 19) have demonstrated that much larger amounts of phosphorus are held in the adsorbed form when the pH of the soil is low. This point is illustrated in the Marietta data by plot 32, which in 1931 had approximately 28 per cent more adsorbed phosphorus than the other two plots and a pH

of 5.5 compared with pH levels of 7.0 and 7.1 for the other two. The addition of lime to this plot after 1931 raised the pH to 7.3, and the percentage of adsorbed phosphorus dropped into line with the other plots as measured in 1938. The small but consistent shift toward greater adsorption by the plots in 1938 is not accounted for by any of the data available.

It is interesting to note that the decrease of phosphorus in plot 31 between 1931 and 1938 occurred with respect to all three fractions—acid-soluble, adsorbed, and flush. This suggests that the plants were utilizing all three forms either directly or indirectly. Evidence on this point that might be gained by a comparison of plots 31 and 34 with plot 32 in 1931 is masked by the effect of the differences in pH levels on these plots.

Since the plant response data have been reported in detail by Bushnell (7), only the pertinent points will be mentioned here. These plots are interesting

TABLE 2

*Quantities of different forms of available phosphorus found in the Marietta plots*

| YEAR SAMPLED | PLOT | TREAT-MENT* | AVAILABLE PHOSPHORUS FOUND | | | | | | | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Acid-soluble | | Adsorbed | | Flush | | |
| | | | lbs./A. | lbs./A | per cent | lbs./A. | per cent | lbs./A. | per cent | |
| 1931 | 31 | 4-10-8 | 231 | 59 | 25.5 | 142 | 61.5 | 30 | 13.0 | 7.0 |
| 1931 | 32 | 4- 0-8 | 102 | 9 | 8.8 | 91 | 89.2 | 2 | 2.0 | 5.5 |
| 1931 | 34 | 4-10-0 | 265 | 69 | 26.0 | 162 | 61.2 | 34 | 12.8 | 7.1 |
| 1938 | 31 | 4- 0-8 | 182 | 41 | 22.6 | 125 | 68.6 | 16 | 8.8 | 7.1 |
| 1938 | 32 | 4-12-8 | 247 | 51 | 20.7 | 168 | 68.0 | 28 | 11.3 | 7.3 |
| 1938 | 34 | 4-20-8 | 467 | 111 | 23.8 | 302 | 64.6 | 54 | 11.6 | 7.0 |

* For 16 years previous to 1931 the annual rate of application was 640 pounds per acre. From 1931 to 1938 the annual rate of application was 1,000 pounds per acre.

from this standpoint because the phosphorus levels vary in and above the range of crop response, which makes it possible to correlate the soil test values with the amount necessary for maximum yields. Plot 31, for instance, gave maximum yields 4 years after the phosphorus applications had been discontinued. After this time the phosphorus level fell below the point where it could maintain maximum yields of tomatoes without phosphorus applications. This suggests that a soil test value about half way between that of plot 31 in 1931 and that in 1938 should indicate the threshold where no further response to phosphorus fertilizers could be expected. This value is approximately 200 with the PA2 extraction. At the end of 8 years, the phosphorus level was still high enough to maintain maximum yields of cabbage. This indicates that the threshold for cabbage is at or below the soil test on plot 31 at that time, which would be 182. Sweet corn had shown no response to phosphorus fertilizers during the entire experiment. The threshold for sweet corn should then be at or below the lowest value obtained, which would be that for plot 32 in 1931. This is a PA2 test of 102.

*Columbus plots*

The results of the PA2 extractions on the Columbus plots also show a good correlation with the fertilizer applications (table 3).   The average PA2 value for the untreated, standard phosphorus, and double phosphorus treatment plots were 412, 778, and 1173 respectively.   The increases over the untreated plots account for approximately 49 per cent of the phosphorus applied in both cases.

The high pH level of these plots suggests low adsorption.   This is borne out by the data which indicate that an average of only 36.5 per cent of the phosphorus is held in this manner.   It is interesting to note that this is only about one half the amount adsorbed by the Marietta soils in a similar pH range.   This emphasizes the fact brought out by several papers that other factors such as the kind

TABLE 3

*Quantities of different forms of available phosphorus found in Columbus plots*

| PLOT | TREATMENT* | AVAILABLE PHOSPHORUS FOUND | | | | | | | pH |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Acid-soluble | | Adsorbed | | Flush | | |
| | | *lbs./A.* | *lbs./A.* | *per cent* | *lbs./A.* | *per cent* | *lbs./A.* | *per cent* | |
| 3 | 8- 0-12 | 370 | 153 | 41.3 | 133 | 36.0 | 84 | 22.7 | 7.4 |
| 3a | 8- 0-12 | 615 | 283 | 46.0 | 203 | 33.0 | 129 | 21.0 | 7.3 |
| 3b | 8- 0-12 | 252 | 97 | 38.5 | 104 | 41.3 | 51 | 20.2 | 7.4 |
| 5 | 8-20-12 | 645 | 248 | 38.5 | 247 | 38.3 | 150 | 23.2 | 7.1 |
| 5a | 8-20-12 | 785 | 303 | 38.5 | 326 | 41.6 | 156 | 19.9 | 6.7 |
| 5b | 8-20-12 | 905 | 343 | 37.9 | 328 | 36.2 | 234 | 25.9 | 7.2 |
| 7 | 8-40-12 | 1145 | 460 | 40.2 | 385 | 33.6 | 300 | 26.2 | 7.2 |
| 7a | 8-40-12 | 1115 | 400 | 35.9 | 499 | 44.7 | 216 | 19.4 | 6.5 |
| 7b | 8-40-12 | 1260 | 720 | 57.2 | 300 | 23.8 | 240 | 19.0 | 6.8 |

* All plots received an annual application of 1,000 pounds per acre.

of clay minerals (18) and the amount of sesquioxides (9, 10, 14, 18) present influence the amount held in this form.

If the threshold values obtained from the Marietta experiments are used as a criterion, no yield increases would be expected from the use of phosphorus fertilizer on the Columbus plots, since the lowest PA2 value obtained is above the highest threshold indicated by the Marietta experiments.   Up to the time of sampling for these tests no significant yield increases had been obtained.

*Cook County plots*

Bray and Dickman (4) have reported that rock phosphate tends to accumulate in the acid-soluble form, whereas superphosphate tends to accumulate in the adsorbed form.   This tendency, together with the fact that all the Cook County plots received an initial application of 1 ton of rock phosphate, probably accounts for the relatively high percentage of acid-soluble forms on these plots, which are in a relatively low pH range.   It will be noted (table 4) that in replication 5 each

plot has a lower pH than the plot in replication 4 which has had a similar treatment. Without exception, the acid-soluble fraction is less and the adsorbed fraction more, on a percentage basis, at the lower pH level. This is in line with the observations on the Marietta plots. The flush value is also less at the lower pH level, indicating less of the easily available forms.

The effect of increasing the superphosphate: rock phosphate ratio in the fertilizer on the total available phosphorus in the soil is shown to be influenced by the pH of the soil. In replication 4, at a higher pH level, there is a definite increase in the total available phosphorus as the relative amount of superphosphate in the fertilizers increases. This is due primarily to increases in the adsorbed and flush forms. In replication 5, at a lower pH level, this trend is almost eliminated. This is due to greater effectiveness of the rock phosphate, as indi-

TABLE 4

*Quantities of different forms of available phosphorus found in Cook County plots*

| REPLICA-TION | PLOT | TREATMENT* | | AVAILABLE PHOSPHORUS FOUND | | | | | | | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sp | RP | Total | Acid-soluble | | Adsorbed | | Flush | | |
| | | *per cent* | *per cent* | *lbs./A.* | *lbs./A.* | *per cent* | *lbs./A.* | *per cent* | *lbs./A.* | *per cent* | |
| 4 | 13 | 0 | 12 | 205 | 113 | 55.1 | 82 | 40.0 | 10 | 4.9 | 5.7 |
| | 14 | 4 | 8 | 245 | 118 | 48.2 | 112 | 45.7 | 15 | 6.1 | 5.7 |
| | 15 | 8 | 4 | 290 | 144 | 49.6 | 126 | 43.5 | 20 | 6.9 | 6.0 |
| | 16 | 12 | 0 | 327 | 127 | 38.8 | 169 | 51.7 | 31 | 9.5 | 6.2 |
| 5 | 17 | 0 | 12 | 245 | 113 | 46.2 | 122 | 49.7 | 10 | 4.1 | 5.3 |
| | 18 | 4 | 8 | 247 | 105 | 42.4 | 133 | 54.0 | 9 | 3.6 | 5.2 |
| | 19 | 8 | 4 | 245 | 93 | 38.0 | 138 | 56.3 | 14 | 5.7 | 5.6 |
| | 20 | 12 | 0 | 265 | 75 | 28.4 | 177 | 66.7 | 13 | 4.9 | 5.1 |

* All plots received an initial application of 1 ton of rock phosphate. Following this they received an annual application of 800 pounds per acre of 4-12-4 in which the amount of superphosphate (Sp) and rock phosphate (RP) were varied as indicated.

cated by the increase in the total available phosphorus in plot 17 as compared with 13, and to a decrease in the effectiveness of superphosphate, as indicated by a similar comparison of plots 20 to 16. It is interesting to note that the increase in plot 17 over plot 13 is entirely in the adsorbed fraction, indicating that, although the rock phosphate is more rapidly brought into solution, the dissolved form is more rapidly adsorbed. The decrease in the total in plot 20 as compared to 16 is probably due to the more rapid conversion of adsorbed forms into more tightly held forms that are not extractable by this method. This phenomenon has been demonstrated by Kurtz, DeTurk, and Bray (13).

The fact that the trends in the flush forms exhibit some of the tendencies of both the acid-soluble and the adsorbed forms is considered as evidence that both these forms are included in this extraction.

Beans, head lettuce, and spinach have not shown consistent differences on these plots. Tomatoes, however, have given maximum yields at levels slightly above those of plots 15 and 19. The PA2 tests on these plots—290 and 245—are higher

than the 200 threshold obtained in the Marietta experiments. This may be due to the large acid-soluble fraction caused by the rock phosphate, which makes the total too high, and suggests that caution may be necessary in interpreting the results of tests on fields that have received large amounts of this form of fertilizer.

## SUMMARY

A modification of a soil test procedure developed by Bray and his associates is outlined. The extraction methods used delineates more clearly between the acid-soluble and adsorbed forms of available phosphorus.

It is demonstrated that interference of fluoride in the extracting solution with the molybdenum blue reaction becomes greater as the amount of phosphorus in the extract increases. This interference becomes significant in the range of phosphorus levels found in extracts of soils that have received large amounts of phosphorus-fertilizer.

Analyses are presented from three vegetable fertilizer experimental fields which had been receiving different amounts or kinds of phosphorus fertilizer for 10 or more years before sampling. The total available phosphorus indicated by the analyses shows a close correlation with the amount applied.

Effects of the pH of the soil, kind of phosphorus fertilizer used, and other factors on the relative amounts of acid-soluble and adsorbed forms of phosphorus revealed by the analyses are shown to agree with the literature dealing with this subject.

The threshold at which various crops fail to respond to phosphorus fertilizer applications as determined by the Marietta experiments are calibrated with this soil test procedure. The thresholds, in pounds of available phosphorus found per acre by the PA2 extraction method, were as follows; tomatoes 200, cabbage 182 or less, sweet corn 102 or less. Failure of the phosphorus treatments in the Columbus plots to increase yields may be explained by the fact that the PA2 values are all above the highest threshold obtained in the Marietta experiments. That tomatoes gave a response to levels above 200 in the Cook County plots is attributed to the fact that large amounts of rock phosphate had been used. This tended to make the estimate of the fertility level by this procedure too high.

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# EFFECT OF VARIOUS MULCHING MATERIALS ON ORCHARD SOILS[1]

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The use of mulches in Michigan orchards is generally recommended, and it is believed that in the future more and more fruit growers will shift to some kind of mulch culture system. Mulches are believed to be beneficial chiefly through their influence on soil moisture relations and their contribution to the supply of plant nutrient elements and organic matter in the soil. Detrimental effects have been observed, however with their use under certain conditions. Field observations indicate that nitrogen deficiency may occur in soils where carbonaceous mulching materials have been used, particularly on soils low in organic matter. In other instances it has been observed that fruit has failed to mature properly and to develop desirable color where nitrogenous mulching materials have been used; this has been particularly noticeable on the more fertile soils.

Moisture is perhaps the greatest limiting factor in fruit production in Michigan, particularly on the shallower and more sandy soils and where a sod culture system is used. Under these conditions use of some sort of mulching material around the trees is recommended, but just how effective these mulches are in controlling or increasing available soil moisture is a question frequently raised. The idea is sometimes expressed that certain kinds of mulches intercept and absorb such a large share of the rainfall that less water is actually available for the plants than without the mulch. In such instances it is believed that the absorption and subsequent evaporation of moisture from the mulch may be greater than the reduction in loss of water from the soil by evaporation.

To provide some information on these various questions, an experiment involving the use of lysimeters was started in the fall of 1939. Thus, the primary object of this experiment was to determine the effect of different mulching materials on leaching losses of soil nitrogen and on evaporation losses of soil moisture. This experiment also offered opportunity to study the effect of mulching materials on the quantity of exchangeable bases in the soils. It is the purpose of this report to present the results of this 4-year lysimeter study involving a comparison of several mulching materials on the surfaces of three soil types under similar conditions and without growing plants.

Numerous investigators have studied moisture and nitrate conditions under artificial mulches, but only a few of the reports are cited in this paper. In many of the studies reported only one type of mulching material was used and on only one type of soil. For the most part the experiments included growing crops, which made interpretation of results in many instances rather difficult.

In regard to artificial mulches, the term "mulch" has a wide interpretation. Anything from sparse grass grown and allowed to lie where it falls to straw or other material spread to a depth of several inches has been designated "mulch." There are thus many kinds of mulching materials and several ways in which the same mulching material may be used. According to the literature reviewed, the same type of mulching material may behave quite differently under different soil and climatic conditions.

It has been reported (1, 2) that nitrate accumulation on uncropped land to a depth of 7 inches was decidedly depressed by an 8-ton application of straw mulch. This depression in nitrification was believed due to a lack of aeration because of higher moisture content under the mulch. The effect could be overcome in about 2 months by removing the straw mulch.

Investigators at the Massachusetts Agricultural Experiment Station (3, 4, 10, 11) have found increased nitrate accumulation in orchard soils where 6 to 8 tons of straw and waste hay were applied as a mulch. This increase was noted after 3 years. During the first 3 years of the experiment, nitrates accumulated to a slight extent only. The hypothesis was advanced that nitrification occurs mainly in the lower, humified layer of the mulch in contact with the soil rather than in the soil proper, and, by leaching, the nitrates are carried into the soil.

The Nebraska Agricultural Experiment Station has reported (8) that the residues of grain crops left on the surface have shown a tendency to reduce nitrate production early in the season, as compared with residues turned under or absent, probably because the residues on the surface delayed warming of the soil in spring. They have not displayed any clear-cut tendency to reduce nitrate production during warm parts of the year. By preventing runoff, increasing intake, and reducing evaporation of water, residues induced deeper storage of moisture in the soil. It was also pointed out that where the moisture supply is abundant, an increase in moisture intake through residues on the surface might lead to loss of nitrates through leaching to depths below the root zone.

Soil temperatures can be reduced considerably in spring and summer by large amounts of residue, especially bright straw (7, 8, 9). Early spring seemed to be the only time when residue cover might lower soil temperature enough to affect nitrification adversely. Mulches also delay cooling of soils in late fall and winter.

Bushnell and Welton (5) in studying some effects of straw mulch on yield of potatoes found that the mulch reduced soil temperature below that of cultivated plots, conserved moisture content, and depressed nitrates.

In a recent report by Dawson (6), where effects of wheat straw residues and lespedeza residues are compared, young wheat plants showed a yellowing in early spring as growth started. After a time the yellowing disappeared on plots treated with legume residues but continued on those receiving straw. Plots receiving legume residues consistently outyielded those receiving wheat straw. Soil nitrates tended to be slightly higher under legume residues than under straw. In view of the fact that nitrate utilization was apparently greater where legume residues were used, it was assumed that nitrification was somewhat greater under the legume treatments than under the straw.

## METHODS AND PROCEDURES

Cylindrical lysimeters, 40 inches in diameter and 15 inches deep, of galvanized iron coated with asphalt paint were used. About 7 inches of surface soil was placed in each lysimeter and the walls were extended far enough above the soil to keep the mulch in place and prevent loss of water by run-off. The lysimeters were placed in the ground so that the surface of the soil in them was at the same level as the soil on the outside. Three soils—Coloma sand, Hillsdale sandy loam, and Miami silt loam—were used. Before being placed in the lysimeters, they were screened to remove stones or coarse crop refuse.

Mulches of alfalfa hay, straw, and straw plus nitrogen were applied to each of the three soils; other lysimeters of each soil received no mulch and the weeds were kept out by frequent cultivation. Even in the absence of weeds, the soil in the "no mulch" lysimeters was cultivated frequently to maintain a 2- to 3-

TABLE 1

*Nitrate content of soils at start of experiment, and total nitrogen content of mulching materials used*

| SOIL | NITRATE NITROGEN IN SOIL | MULCHING MATERIAL* | TOTAL NITROGEN IN MULCHING MATERIAL |
|---|---|---|---|
| | *mgm./100 gm.* | | *per cent* |
| Hillsdale | 15.2 | Shavings | 0.10 |
| Miami | 2.3 | Peat† | 2.35 |
| Coloma | 3.3 | Straw | 0.43 |
| | | Sawdust | 0.15 |
| | | Alfalfa | 2.24 |

\* No total nitrogen determinations were made on corn stover or gravel.
† Peat contained 6.2 mgm. nitrate N per 100 gm. oven-dry material.

inch soil mulch. Additional mulches of peat, shredded corn stover with and without nitrogen, sawdust, wood shavings, and gravel were used on the Hillsdale soil. The coarser and more bulky mulching materials (alfalfa hay, corn stover, and straw) were applied about 5 to 6 inches thick and the other materials (shavings, sawdust, pulverized peat, and gravel) were about 1 to 2 inches thick. The straw, alfalfa, and corn-stover were replenished as often as needed to maintain a good mulch. Nitrogen was applied in the form of ammonium sulfate to some of the straw and corn stover mulches at the rate of 2 ounces per lysimeter in 1940, 1941, and 1943. All treatments were made in triplicate. Total nitrogen analyses were made on all mulching materials used except corn stover and gravel (see table 1).

At the beginning of the experiment (October, 1939) samples of soil were collected from the lysimeters for determinations of ammonia and nitrate nitrogen (see table 1). In September, 1943, samples of soil were again collected from each lysimeter for pH, ammonia, and nitrate determinations and for base-exchange studies. In taking these samples, five borings representing the entire depth of the soil were made in each lysimeter.

Following each rain of any consequence, the total quantity of percolate was determined for each lysimeter, and a pint sample was collected for soluble nitrogen determinations. The nitrate determinations were made by the reduction method using Devarda's alloy.

In this report, the quantity of percolating water collected is used as an indication of the effectiveness of each treatment in increasing the amount of available water: the greater the amount of percolate, the more effective is the mulch. In other words, if a relatively small amount of percolate is obtained with one treatment in comparison to another on the same kind of soil, it means that a relatively large amount of water must have been lost by evaporation.

No plants were grown in the lysimeters, and no water was applied other than that added by rainfall.

<div align="center">RESULTS</div>

<div align="center">*Effect of mulching materials on moisture loss*</div>

In 1940 (12) a preliminary report for the first year was made on the effect of mulching materials on moisture loss. The data presented at that time showed that, except for the peat mulch, at least twice as much percolate was collected from the mulched soils as from the unmulched soils. All other mulches were about equally effective in decreasing moisture losses by evaporation, and they seemed to be as effective on one soil as another. Pulverized peat was ineffective in increasing the quantity of percolate; results with it were similar to those obtained with no mulch. It was noted that during periods of light rainfall no percolate was collected from the unmulched soils or from the soil with peat mulch; at the same time considerable quantities of percolate were collected from the soils with all mulching materials other than peat. This, as was pointed out, gives emphasis to the value of effective mulches during the drier seasons of the year, particularly on the more droughty soils.

Data for the total amount of percolate collected for the entire period of the experiment are shown in table 2. The data are expressed in terms of pounds of water, and each figure represents the average of three lysimeters. The figures represent the total quantity of rainfall caught by the lysimeters less the amount of water absorbed by the soil and mulch and that lost by evaporation.

A comparison of straw, straw plus nitrogen, and alfalfa mulches on each of the three soils shows that they were essentially as effective on one soil as another and that there were no significant differences between the mulches for any particular soil. In each instance where a mulch was applied, the amount of percolate collected was more than 50 per cent greater than where no mulch was applied. This difference can be attributed to the much greater losses of water by evaporation from the unmulched than from the mulched soils. It may be of interest to note that about the same quantities of percolate were collected from each of the three unmulched soils. In other words, the amount of water lost by evaporation was about the same for all soils.

The effectiveness of various mulching materials on moisture loss from Hills-

dale sandy loam is shown in table 2 to be in the following descending order: straw, corn stover, alfalfa, shavings, gravel, sawdust, and peat. (In this arrangement, the mulches receiving additional nitrogen are not included.) With the exception of the peat, it is doubtful whether the differences among the other mulching ma-

TABLE 2

*Effect of different mulching materials on amount of percolate collected from lysimeters filled with Hillsdale, Miami, and Coloma soils*

| TYPE OF MULCH AND TREATMENT | TOTAL PERCOLATE COLLECTED FROM START OF EXPERIMENT UP TO AND INCLUDING | | | |
|---|---|---|---|---|
| | Dec. 28, 1940 | Nov. 29, 1941 | Nov. 19, 1942 | Sept. 9, 1943 |
| | *lbs.* | *lbs.* | *lbs.* | *lbs.* |
| *Hillsdale soil* | | | | |
| Straw.............................. | 865 | 1511 | 2076 | 2696 |
| Corn stover*......................... | 850 | 1557 | 2026 | 2652 |
| Shavings, wood...................... | 912 | 1486 | 1980 | 2549 |
| Sawdust............................ | 908 | 1444 | 1880 | 2462 |
| Alfalfa............................. | 860 | 1434 | 1989 | 2623 |
| Gravel............................. | 948 | 1498 | 1950 | 2544 |
| Straw and N........................ | 900 | 1558 | 2137 | 2752 |
| Corn stover* + N.................... | 840 | 1274 | 1754 | 2383 |
| Average for all mulches except peat.... | 885 | 1345 | 1974 | 2583 |
| Peat............................... | 576 | 891 | 1191 | 1685 |
| Check (no mulch)................... | 580 | 940 | 1164 | 1590 |
| *Miami soil* | | | | |
| Straw.............................. | 925 | 1545 | 2102 | 2733 |
| Alfalfa............................. | 931 | 1496 | 2051 | 2676 |
| Straw + N......................... | 932 | 1564 | 2107 | 2718 |
| Average for all mulches............. | 929 | 1535 | 2120 | 2709 |
| Check (no mulch)................... | 620 | 985 | 1251 | 1719 |
| *Coloma soil* | | | | |
| Straw.............................. | 910 | 1563 | 2125 | 2751 |
| Alfalfa............................. | 905 | 1443 | 1969 | 2602 |
| Straw + N......................... | 906 | 1564 | 2138 | 2772 |
| Average for all mulches............. | 907 | 1523 | 2077 | 2708 |
| Check (no mulch)................... | 608 | 974 | 1223 | 1667 |

* Corn stover applied April, 1940; all other mulches applied October, 1939. Straw, alfalfa, and corn stover mulches replenished June, 1941, and June, 1943.

terials are significant. There is some indication, however, that the sawdust behaves more like the peat than do the other materials. Apparently the peat had such a great absorptive capacity for water that with light rains or with long intervals between rains very little water reached the soil or at least not enough to permit percolation through the soil. It is evident that under these conditions the evaporation of water from the mulch itself was enormous. The results ob-

tained with peat indicate that it would be of little value as a mulch for decreasing the loss of available water in the soil, particularly during the drier seasons of the year. Another objectionable feature of using peat as a mulch is the difficulty in keeping down weeds.

The relatively small quantity of percolate for the corn stover plus nitrogen on the Hillsdale soil can be attributed to the fact that this mulch was not replenished frequently enough. The nitrogen apparently hastened its decomposition, and at times only a scant mulch covered the soil.

### Effect of mulching materials on soil nitrates

The effects of different mulching materials on the quantity of soluble nitrogen lost by leaching are shown in table 3 for different intervals during the experiment. In the beginning, ammonia and nitrate nitrogen in the leachates were determined separately but the quantities of ammonia nitrogen were so small this practice was discontinued and the procedure modified to include both forms of nitrogen simultaneously. Throughout this report the values will be referred to as "nitrate."

The quantity of nitrate in the leachates was less from the mulched soils than from the unmulched soils except where alfalfa was used and also from two of the soils that had received straw mulch plus ammonium sulfate. Straw mulch caused a marked decrease in leaching losses of nitrates on all three soils and particularly on the Hillsdale soil. It should be recalled that much greater quantities of water leached through the mulched than the unmulched soils, yet less nitrate was removed.

The data for the Hillsdale soil show that with all mulches, except alfalfa, production of nitrates was lower than in the unmulched soil. It is especially significant to note that less loss (or production) of nitrates occurred with gravel mulch than with no mulch, yet the gravel in no way contributed directly to the organic matter or nitrogen content of the soil or modified the food supply of the microorganisms. In this case the differences in the leaching losses must have been due to the depressive effect of the mulch on the production of nitrates in the soil. During the 4 years, 60 per cent more water percolated through gravel-mulched than unmulched soil. Furthermore, the Hillsdale soil had a rather high nitrate content to begin with (table 1), and at the end of the first year nitrate losses were greater for the gravel mulch but thereafter losses were less than with the unmulched soil. The apparent decrease in production of nitrates under the mulch was probably due to poorer aeration, brought about primarily by the higher soil moisture content, and to somewhat lower temperature. In May, 1943, temperature readings were taken of the soils 3 inches below the surface in each lysimeter. These readings were taken in the early afternoon on three different days. Averaging the values obtained under all mulches showed that the temperature was 4°C. less than for the unmulched soils. The temperature of the soil under the gravel mulch was less than 1° below the unmulched soil. Thus the decreased production of nitrates appears to have been more of a function of aeration than of temperature.

In view of the results obtained with gravel mulch, it is believed that the marked

decreases in leaching losses of nitrates from Hillsdale soil receiving straw, corn stover, shavings, or sawdust mulches were due to a decrease in production of nitrates rather than to the assimilation of nitrates resulting from these carbonaceous materials.

Leaching losses of nitrates under the peat mulch were less than from the un-

TABLE 3

*Effect of different mulching materials on quantity of soluble nitrogen in leachate collected from lysimeters filled with Hillsdale, Miami, and Coloma soils*

| TYPE OF MULCH AND TREATMENT | SOLUBLE NITROGEN IN LEACHATE COLLECTED UP TO AND INCLUDING | | | |
|---|---|---|---|---|
| | Dec. 28, 1940 | Nov. 29, 1941 | Nov. 19, 1942 | Sept. 9, 1943 |
| | gm. | gm. | gm. | gm. |
| *Hillsdale soil* | | | | |
| Straw.............................. | 7.5 | 8.8 | 9.7 | 10.7 |
| Corn stover*...................... | 5.6 | 7.2 | 8.3 | 9.2 |
| Shavings, wood.................... | 10.4 | 12.3 | 13.8 | 15.2 |
| Sawdust........................... | 9.5 | 11.9 | 12.4 | 13.0 |
| Peat.............................. | 9.1 | 14.5 | 17.0 | 20.4 |
| Alfalfa........................... | 9.9 | 17.6 | 22.1 | 24.9 |
| Gravel............................ | 11.5 | 14.9 | 17.3 | 19.1 |
| Check (no mulch).................. | 9.9 | 16.9 | 20.5 | 23.1 |
| Straw + N......................... | 10.1 | 15.3 | 15.8 | 17.8 |
| Corn stover* + N.................. | 8.6 | 19.3 | 21.0 | 22.6 |
| *Miami soil* | | | | |
| Straw............................. | 3.5 | 6.3 | 7.8 | 8.4 |
| Alfalfa........................... | 7.9 | 13.7 | 22.1 | 25.5 |
| Straw + N......................... | 7.5 | 13.9 | 15.0 | 18.0 |
| Check (no mulch).................. | 6.5 | 10.6 | 13.4 | 15.4 |
| *Coloma soil* | | | | |
| Straw............................. | 5.8 | 8.2 | 9.3 | 10.8 |
| Alfalfa........................... | 14.2 | 19.7 | 31.0 | 37.0 |
| Straw + N......................... | 10.4 | 16.7 | 19.2 | 23.5 |
| Check (no mulch).................. | 6.3 | 10.2 | 12.5 | 14.9 |

* Corn stover applied April, 1940; all other mulches applied October, 1939. Straw, alfalfa, and corn stover mulches replenished June, 1941, and June, 1943.

mulched soil although the peat itself had a fairly high nitrate content (see footnote table 1). Furthermore, losses with the alfalfa mulch, on the Hillsdale soil, were only slightly greater than from the unmulched soil. With this type of material it is likely that some nitrates were produced in the mulch itself regardless of soil conditions underneath. The production of nitrates where ammonium sulfate was applied with either straw or corn stover on this soil was somewhat less than in the unmulched soil as measured by the amount found in the leachings and in the soil at the conclusion of the experiment (table 4).

In the Miami and Coloma soils, nitrate production was much greater with the alfalfa and straw plus nitrogen mulches than in the unmulched soils. The differences were greater for the Coloma than for the Miami soil, probably because of better aeration in the coarser textured soil.

If the decrease in the amount of nitrates recovered in the leachates from the soil under the straw mulch was due to the assimilation of nitrates by microorganisms it would be expected that this nitrogen would be eventually released and in time the quantity recovered from the mulched soil would exceed that from the unmulched soil. That this condition did not exist in either soil is clearly shown in table 3; in fact, the differences between the mulched and unmulched soils increased rather than decreased with time. There is no indication of assimilation

TABLE 4

*pH and nitrate nitrogen content of soils in lysimeters at end of experiment*

| MULCHING MATERIAL | N IN SOIL | pH* | MULCHING MATERIAL | N IN SOIL | pH* |
|---|---|---|---|---|---|
| | *mgm./100 gm.* | | | *mgm./100 gm.* | |
| *Hillsdale soil* | | | *Miami soil* | | |
| Straw............... | 3.2 | 5.8 | Straw............... | 2.1 | 5.7 |
| Corn stover.......... | 2.7 | 6.1 | Alfalfa.............. | 4.2 | 6.1 |
| Shavings, wood....... | 4.2 | 5.7 | Straw + N......... | 2.3 | 4.8 |
| Sawdust.............. | 2.0 | 5.6 | No mulch........... | 2.0 | 5.6 |
| Peat................. | 3.3 | 5.5 | *Coloma* | | |
| Alfalfa hay.......... | 3.9 | 6.1 | | | |
| Gravel.............. | 3.7 | 6.1 | Straw............... | 1.2 | 5.9 |
| No mulch............ | 2.7 | 5.7 | Alfalfa.............. | 3.6 | 5.9 |
| Straw + N.......... | 2.6 | 5.4 | Straw + N......... | 2.0 | 5.2 |
| Corn stover + N..... | 2.6 | 5.4 | No mulch........... | 1.0 | 6.1 |

of nitrates and their subsequent release. All the evidence suggests that the straw mulch over a period of 4 years actually depressed nitrate production in the soil under the conditions of this experiment.

Relative rates of nitrate production (as measured by leaching losses) under alfalfa mulch for the three different soils are shown in table 3. The lowest production occurred in the Hillsdale, followed in order by the Miami and Coloma soils. The total production of nitrates in the Hillsdale soil under the alfalfa mulch during the first year was slightly less than for the unmulched soil and only slightly greater during the 4 years. On the other hand, nitrate production was relatively rapid in the Coloma soil and the total amount collected in the leachate was 50 per cent greater than from the Hillsdale soil. The total amount of nitrates leached from the unmulched soils subtracted from the values obtained for the corresponding soils with alfalfa mulch (table 3) should indicate roughly the relative rates of nitrification in the three soils. These values in terms of grams of nitrogen (for the 4 years) are 1.8, 10.1, and 22.1 respectively for the Hillsdale,

Miami, and Coloma soil. These enormous differences cannot be explained on the basis of varying amounts of leaching (table 2); with like treatments there was little difference in the amount of percolate for the three soils.

Results of ammonia and nitrate determinations on the soil in each lysimeter at the close of the experiment (table 4) reveal that differences among the soils with corresponding mulches were not large. The values were highest under alfalfa mulch on the Miami and Coloma soils and next to the highest on the Hillsdale soil. For some unexplained reason the content of ammonia and nitrate nitrogen in the Hillsdale soil with the shavings is higher than that with alfalfa.

Nitrate values for the Coloma soil in all instances were somewhat less than for corresponding treatments on the Hillsdale or the Miami soil. Obviously the differences in the quantities of nitrate in the soils were not sufficient to account for the differences in leaching losses.

### Effect of mulching materials on exchangeable bases

The effect of the different mulching materials on the quantity of exchangeable calcium, magnesium, and potassium in the three soils is shown in table 5. A very definite increase occurred in the total quantity of exchangeable bases in all soils where alfalfa was used and a very definite decrease occurred in all instances where ammonium sulfate was added to the mulches (corn stover or straw). Straw mulch appeared to bring about an increase in the exchangeable bases in the Hillsdale soil but not in the Miami or Coloma soils.

In comparison to the unmulched Hillsdale soil, wood shavings, sawdust, and peat decreased the quantity of exchangeable bases found in the soil, although an increase (less leaching loss) occurred where the gravel mulch was used.

Exchangeable calcium, magnesium, and potassium in the unmulched Hillsdale soil comprised 66, 14, and 4 per cent respectively of the base-exchange capacity. The corresponding values for the Miami soil were 70, 18, and 2, and for the Coloma soil 65, 18, and 3. More pronounced changes in the quantities of either magnesium or potassium occurred in the mulched than in the unmulched soils. In comparing the soils receiving the alfalfa mulch with the unmulched soils it is noted that the quantities of exchangeable calcium and potassium were considerably greater in all three soils and magnesium was higher in only the Hillsdale soil.

The content of exchangeable potassium was increased by the straw mulch on all three soils. This is in agreement with results at the Ohio Station (13) where increased available potassium occurred under straw-mulched trees.

There was a definite decrease in the pH in all soils under mulches which had received ammonium sulfate (table 4). In the Hillsdale soil the pH decreased somewhat under the sawdust and peat mulches and increased somewhat under the straw, corn stover, alfalfa, and gravel mulches in comparison to the unmulched soil. Similar results were obtained for the Miami soil with alfalfa and straw mulches, but in the Coloma soil the pH values were somewhat less under the mulches. It is of interest to note that the sawdust mulch after 4 years lowered the pH of the Hillsdale only 0.1 of a unit.

DISCUSSION

In considering movement of moisture through the lysimeters, it is obvious that no large amount of water would move through the mulch into the soil until the mulch approached saturation. Nor would drainage water appear until the soil

TABLE 5

*Effect of different mulching materials on quantity of exchangeable calcium, magnesium, and potassium in Hillsdale, Miami, and Coloma soils\**

| TYPE OF MULCH AND TREATMENT | BASE-EXCHANGE CAPACITY OF SOIL | EXCHANGEABLE BASES† AND PERCENTAGE OF BASE-EXCHANGE CAPACITY | | | | | | TOTAL EXCHANGEABLE Ca, Mg, AND K† | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca | | Mg | | K | | m.e. | Percentage of Base Exchange Capacity |
| | me./100 gm. | m.e. | per cent | m.e. | per cent | m.e. | per cent | | |
| *Hillsdale soil* | | | | | | | | | |
| Straw.................... | 9.10 | 6.08 | 67 | 1.40 | 15 | 0.73 | 8 | 8.21 | 90 |
| Corn stover‡........... | 9.81 | 6.03 | 62 | 1.92 | 20 | 1.00 | 10 | 8.95 | 91 |
| Shavings, wood.......... | 8.20 | 5.33 | 65 | 1.03 | 13 | 0.31 | 4 | 6.67 | 81 |
| Sawdust................. | 8.31 | 4.73 | 57 | 0.88 | 11 | 0.26 | 3 | 5.87 | 71 |
| Peat.................... | 9.23 | 6.00 | 65 | 1.09 | 12 | 0.20 | 2 | 7.29 | 79 |
| Alfalfa................. | 9.45 | 6.93 | 73 | 1.42 | 15 | 0.80 | 9 | 9.15 | 97 |
| Gravel.................. | 9.37 | 7.22 | 77 | 1.23 | 13 | 0.22 | 2 | 8.67 | 93 |
| Check (no mulch)....... | 9.15 | 6.02 | 66 | 1.27 | 14 | 0.38 | 4 | 7.67 | 84 |
| Straw + N.............. | 8.85 | 5.37 | 61 | 1.05 | 12 | 0.62 | 7 | 7.04 | 80 |
| Corn stover‡ + N....... | 9.23 | 5.02 | 54 | 1.23 | 13 | 0.81 | 9 | 7.06 | 77 |
| *Miami soil* | | | | | | | | | |
| Straw.................... | 11.66 | 7.90 | 68 | 1.92 | 17 | 0.37 | 3 | 10.19 | 87 |
| Alfalfa................. | 11.77 | 8.58 | 73 | 1.84 | 16 | 0.84 | 7 | 11.26 | 96 |
| Straw + N.............. | 11.07 | 5.01 | 45 | 1.45 | 13 | 0.35 | 3 | 6.81 | 62 |
| Check (no mulch)....... | 10.48 | 7.34 | 70 | 1.87 | 18 | 0.19 | 2 | 9.40 | 90 |
| *Coloma soil* | | | | | | | | | |
| Straw.................... | 4.12 | 2.49 | 60 | 0.49 | 12 | 0.43 | 10 | 3.41 | 83 |
| Alfalfa................. | 4.49 | 3.07 | 68 | 0.54 | 12 | 0.69 | 15 | 4.30 | 96 |
| Straw + N.............. | 3.87 | 1.75 | 45 | 0.45 | 12 | 0.35 | 9 | 2.55 | 66 |
| Check (no mulch)....... | 4.07 | 2.63 | 65 | 0.73 | 18 | 0.11 | 3 | 3.47 | 85 |

\* These analyses were made by Miss Marrianne Unger according to the methods outlined by Peech *et al.* "Methods of soil analysis for soil fertility investigations", 1945, prepared by a committee on uniform methods of analysis.

† The water-soluble ions are included with the exchangeable ions.

‡ See footnote table 3.

had reached its moisture-holding capacity unless cracks or other noncapillary openings had developed through the soil. Evaporation occurred between rains from both the mulch and the soil, and it was necessary that this evaporated moisture be replaced before further percolation was obtained. Thus, as pointed out in an earlier report (12), the amount of percolation is appreciably influenced

by the quantity, intensity, and frequency of rains, the climatic factors affecting evaporation, and the effectiveness of the mulch in decreasing evaporation losses.

The results obtained with peat on moisture losses from soil are particularly significant. The peat appears to have had such a high absorptive capacity for water that with light rains or with long intervals between rains very little water actually reached the soil or at least not enough to permit percolation through the soil to any greater extent than through the unmulched soil. In other words, evaporation of water from the mulch itself was sufficient to offset any beneficial effect of the mulch in decreasing evaporation of water from the soil below. As evidence to support this contention, it is observed that gravel and other mulches of low moisture-absorbing ability were very effective. In view of the fact that peat may not be effective in conserving moisture, at least during certain seasons of the year, and because of the weed problem, it is of doubtful value as a mulching material.

On the whole, the results definitely indicate the value and effectiveness of mulching materials such as straw, corn stover, alfalfa, gravel, shavings, and to a lesser degree sawdust, in the conservation of moisture under Michigan conditions. Under field conditions, by decreasing runoff, increasing intake, and reducing evaporation, mulches may induce a deeper storage of water in the soil and thus an increased available supply for crop use. This is of particular importance in orchards on the more droughty soils, because soil moisture is one of the greatest limiting factors in fruit production under such conditions.

With the exception of alfalfa hay, all mulches, unless supplemented with nitrogen, have been shown to reduce nitrate production over a period of 4 years in comparison to unmulched soil. This reduction is believed due mainly to a higher moisture content and lack of aeration and, in a lesser degree, to a reduction in soil temperature. In general, the least depressive effect on nitrate production occurred in the better aerated soil. As evidence to support the contention that nitrate production was limited because of lack of aeration, it was found that in the Hillsdale soil with alfalfa mulch less nitrate was produced the first year than in the unmulched soil and the total produced for the 4-year period was only slightly greater than in the unmulched soil. In the Coloma sand, however, relatively large quantities of nitrate were produced under the alfalfa mulch. Temperature differences were not great enough to account for these differences in the behavior of the two soils. Furthermore, nitrate production in the Hillsdale soil with gravel mulch was depressed in comparison to the unmulched soil and little difference in temperature was noted under these two conditions. Under field conditions soil aeration beneath a mulch is not likely to be restricted to such a marked degree because of the removal of water by the plants during the growing season.

If in mulched soils nitrification occurs mainly in the lower, humified layer of the mulch in contact with the soil rather than in the soil proper, and by leaching, the nitrates are carried into the soils (4), it is difficult to explain the differences in the production of nitrates in the Hillsdale and Coloma soils under alfalfa mulch.

The depressing effect of straw mulches on nitrates appears to be due to de-

creased production rather than to assimilation of nitrates brought about by the carbonaceous nature of the mulch. If the lower nitrate in the mulched soil was due to the assimilation by microorganisms, then this nitrogen should have been released eventually. There was no evidence in the data reported to indicate a "tie-up" of nitrates with their subsequent release under the straw mulch during the 4-year period. The differences between the straw-mulched and unmulched soils increased rather than decreased with time. Furthermore, the decreased nitrates under gravel mulch, which made no contribution to the food supply of organisms, could not have been due to assimilation. The results of this study indicate that a depression in nitrate production may persist for several years under carbonaceous mulches which are continuously replenished. The necessity for additional nitrogen fertilizer under field conditions where low nitrogen containing mulches are used seems to be clearly indicated, and under a continuous mulch this need may continue for several years. Although in orchards the tree roots develop abundantly just beneath the mulch and throughout the surface horizons, this dense accumulation of roots will remove the excess moisture rapidly following a rain and it is possible that aeration will not limit nitrate production during the summer months.

The data indicate that over a period of years certain types of mulches may contribute materially to the plant nutrient content of the soil while other mulches, such as sawdust, may encourage the loss of basic elements. That the continued use of ammonium sulfate may increase acidity and decrease the base supply in the soil is also clearly indicated.

Thus there are many effects of artificial mulches on soils. Some of those effects may be summarized briefly as follows: By shading the soil, protecting it from direct contact with wind and warm dry air, and by reducing cracking in some soils, mulches may greatly retard evaporation losses of moisture. There is usually a lag in temperature changes in soils under a mulch due to the insulating effect of the mulch and lower vaporization of water; a higher soil moisture means a greater heat requirement to warm it up and greater total loss of heat to lower the temperature. Aeration of soil may be impaired if a persistently higher moisture content should be maintained under a mulch, and in other instances aeration may be improved through the effect of the mulch in modifying soil structure. Nitrate production may be increased or decreased under a mulch depending upon the type of soil, type of mulch, and environmental conditions. In areas of rather intense rain and on sandy soils, mulches may have a greater effect on the translocation of nitrates downward than on the production of nitrates. Mulching materials such as straw, corn stover, and hay will decrease surface runoff and increase absorption of rainfall, whereas materials like peat may reduce the intake of water by absorbing it and later lose it through evaporation. Mulches may prevent the surface soil from "running together" and crusting over as a result of the impact of rain drops and thus increase the intake of water. On the other hand, in light sandy soils where moisture supply is abundant and in seasons of rather heavy rainfall leaching losses of plant nutrient elements may be increased.

In general, artificial mulches will eventually add to the organic matter and plant nutrient content of the soil and may act to conserve the organic supply in the soil by decreasing soil aeration because of higher moisture content. An artificial mulch may cause better distribution of plant roots, a deeper topsoil, and thus a greater feeding zone resulting from more favorable moisture relations. There is often a large accumulation of roots in the surface soil immediately beneath the mulch or in some instances in the mulch itself. In certain areas it is believed that the available moisture supply in the soil may be increased by condensation of moisture from the atmosphere in the mulch.

The behavior or the effectiveness of the mulch system of orchard culture will vary greatly depending, among other things, on the type of soil, kind and condition of mulch, and seasonal conditions such as temperature and amount and distribution of rainfall.

### SUMMARY

The effects of different kinds of mulching materials, some with additional nitrogen fertilizer, on moisture loss, on accumulation and loss of nitrates, and on amount of exchangeable calcium, magnesium, and potassium in the soil have been studied over a period of 4 years with three different soils. Shallow lysimeters were used and each treatment was made in triplicate. Determinations of amount of water and nitrate lost by leaching were made following each rain when the percolate was sufficient.

Straw and alfalfa mulches were equally effective on each of the three soils in decreasing evaporation losses. Their effect on soil moisture loss was about the same for all soils. In each case, except for peat, where a mulch was applied the amount of leachate was more than 50 per cent greater than where no mulch was applied. The amount of water lost by evaporation was essentially the same for the three unmulched soils.

Effectiveness of the different mulching materials in decreasing moisture loss from Hillsdale sandy loam were in the following descending order: straw, corn stover, alfalfa, shavings, gravel, sawdust, and peat. With the exception of peat and possibly sawdust, it is doubtful whether the differences among the other mulching materials were significant.

Peat and, to a much less degree, sawdust have such a high absorptive capacity for water that with light rains or with long intervals between rains relatively little water reached the soil. Vigorous weed growth would be an additional objectionable feature in using peat as a mulch.

These results definitely indicate the value and effectiveness of certain types of mulching materials in the conservation of moisture. Since soil moisture is one of the most important limiting factors in fruit production in Michigan on certain soils, this is of particular importance on the more droughty soils.

Leaching losses of nitrates were greater from unmulched than from mulched soils except where ammonium sulfate was also applied or where alfalfa mulch was used. The results indicate slower nitrification under the mulches. More water percolated through the mulched soils and there was no significant difference in

accumulation of nitrates in the mulched and unmulched soils as determined at end of the experiment.

Less loss (or production) or nitrates occurred with gravel mulch on the Hillsdale soil than with no mulch, yet 60 per cent more water percolated through the gravel-mulched soil. The difference in nitrate loss must have been due to differences in rate of nitrate production in the soil, because the gravel in no way contributed directly to the nitrogen content of the soil or to the food supply of the soil organisms.

Marked decreases in leaching losses of nitrates from the Hillsdale soil receiving straw, corn stover, shavings, or sawdust mulches are believed due to a decrease in production of nitrates in the soil.

Nitrate production (or leaching loss) was much greater in the Coloma and Miami soils and somewhat greater in the Hillsdale soil with alfalfa mulch than in the corresponding unmulched soils. It is believed that the slow rate of nitrate production in the Hillsdale soil with alfalfa mulch is due to a lack of aeration. Fifty per cent more nitrate was produced in the Coloma than in the Hillsdale soil where both had received alfalfa mulch.

At the close of the experiment, differences in the quantity of nitrates in the three soils with the same type of mulching material were not great.

An increase in the total quantity of exchangeable bases occurred in all soils where alfalfa mulch was used. More pronounced changes occurred in exchangeable calcium and potassium than in magnesium.

The total quantity of exchangeable bases increased in the Hillsdale with straw mulch but not in the Miami or the Coloma soil.

The total quantity of exchangeable bases was less in the soil with wood shavings, sawdust, and peat mulches than in the unmulched soil.

A marked decrease in the total quantity of exchangeable bases and in pH occurred in all instances where ammonium sulfate was added to corn stover or straw mulches.

The effectiveness of an artificial mulch varies greatly with the type of soil, kind of mulch, and climatic conditions.

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# SOIL GENESIS FROM A SEDIMENTARY CLAY IN TRINIDAD

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In continuation of our detailed investigations of changes that occur during soil formation between parent rock and derived soil (2, 3), advantage has been taken of the facilities offered by deep well borings, made during geological explorations by an oil company operating in Trinidad, to study the development of a widespread clay soil, provisionally named *Talparo (red) clay soil*. This is derived from a sedimentary deposit named by geologists *Nariva clay*, which occasionally contains calcareous tests of foraminiferal organisms as well as abundant siliceous foraminifera.

Nariva clay is typically a red-weathering marine fissile clay or shale of Oligocene age that was laid down in a shallow muddy sea under conditions similar to those now obtaining in the Gulf of Paria separating Trinidad from the mainland. A typical profile, sampled in detail on the Rio Claro-tabaquite Road[1] by means of auger borings at 5-foot intervals to a depth of 75 feet, was examined in the laboratory by methods described in our previous publications. A petrographic examination of the coarse and fine sand fractions (concentrates) was made.[2]

## DESCRIPTION OF PROFILE SAMPLES

(Auger hole, No. G.6734)

| SAMPLE NUMBER | | DEPTH feet |
|---|---|---|
| G.188 | Characteristic red-weathering clay. Crimson and yellow mottled on pale gray ground. | .5 |
| G.189 | Similar to G.188 in appearance but less crimson and more yellow. | 10 |
| G.190 | Crimson mottling completely dispersed to a mere smear. Yellow mottling very prominent. | 15 |
| G.191 | Similar to G.190 | 20 |
| G.192 | Similar to G.191 but with some rusty brown mottlings. | 25 |
| G.193 | Similar to G.193 but with yellow mottling somewhat more diffuse, masking to some extent the gray ground. Some crimson speckling. | 30 |
| G.194 | Similar to G.193. | 35 |
| G.195 | Less yellow mottling than in G.194; darker gray coloration; still some red specks. Transition layer. | 40 |
| G.196 | Uniformly gray to black shaley clay. | 45 |
| G.197 | Similar to G.196. | 50 |
| G.198 | Similar to G.196. | 65 |
| G.199 | Similar to G.196. | 70 |
| G.200 | Similar to G.196. | 75 |

[1] By A. E. Gunther, late of United British Oilfields, Inc.

[2] By J. C. Griffiths, petrographer of the Trinidad Leaseholds, Ltd., thorough the courtesy of H. H. Suter, Chief Geologist, to whom acknowledgment for this help is made.

From the nature of the samples it was impossible to make rigid selection of characteristic horizons marking the three main stages of soil formation, namely, parent rock, soil parent material, and true soil. For detailed study, the following layers were chosen: (i) top 5 feet, considered to comprise the true solum; (ii) the next 5 feet, comprising the soil parent material; (iii) the horizon at 35 to 40 feet, which shows the first definite color change indicative of weathering (transition layer); (iv) the immediately underlying grayish black clay; and (v) the deepest layer at 70 to 75 feet (parent rock), which should show the least alteration.

### CONDITIONS OF SOIL FORMATION

The climate prevailing over the area where this soil has developed is humid tropical with annual rainfall around 100 inches. The year is divided into a 5-month dry season with mean monthly rainfall between 2.4 and 6 inches, and a 7-month wet season with mean monthly rainfall between 8 and 12 inches. The main direction of water movement in the soil for the greater part of the year is downward. The average daily temperature fluctuates but little around 85°F. and seldom falls below 65°F. or rises above 90°F.

The topography is undulating with average elevation 200 feet above sea level. The area comprises a dissected peneplain carrying a young river system. The red clay mainly occupies the crests and sides of the hills. Surface drainage is thus generally excessive but internal drainage is impeded.

The natural vegetation is evergreen seasonal forest. The chief crop at present is cacao.

Downward percolation of water during rains mainly takes place through abundant and wide cracks developed in dry weather in the upper 3 or more feet of soil. The parent soil material and parent rock exhibit slickenside structure characterized by the occurrence of numerous slip-surfaces caused by tectonic disturbances following deposition. This doubtless assists deep penetration by water.

### PHYSICAL AND CHEMICAL ANALYSIS OF THE SOIL

In table 1 are presented the results of routine laboratory examination of the whole profile. The following facts emerge from them:

#### Texture

Sand content is uniformly low throughout the entire depth, but the moisture at sticky point is higher in the first 25 feet than in the lower 50 feet, suggesting an increase in colloid content upward.

#### Reaction

There is a pronounced differentiation of the profile into four pH horizons, namely, the top true soil and its parent material to 10 feet, which are highly acid, pH 4.6; the next 10 feet, which are slightly acid, pH 6.1 to 6.4; the next 20 feet, pH 7.4 to 7.7; and the parent rock below 40 feet, pH 7.9 to 8.2. These pH changes seem to be caused mainly by leaching of calcium carbonate and to

be associated with the color changes of the iron-bearing component. The very acid horizons are red and red-mottled; the less acid are brownish yellow; the alkaline are transitional, the colors being less of the mottled type and more diffuse; and the highly alkaline parent clay is uniformly grayish black with only occasional red concretionary mottling or speckling.

## Electrical conductivity

Electrical conductivity of soil suspensions is uniformly high but is lower in the top 10 feet, which is obviously highly leached.

### TABLE 1

*Laboratory data for profile samples*

| SAMPLE | LOWER DEPTH | COARSE SAND | FINE SAND | SILT | CLAY | STICKY POINT MOISTURE | NORMAL REACTION | CaCO₃ | ELECTRICAL CONDUCTIVITY | AVAILABLE PHOSPHATE* (P₂O₅) | TOTAL PHOSPHATE (P₂O₅) |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | *feet* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *pH* | *per cent* | *mhos ×10⁻⁴* | *p.p.m.* | *p.p.m.* |
| G.188 | 5 | 1.4 | 4.8 | 19.9 | 66.0 | 38 | 4.6 | 0 | 503 | 10 | 1350 |
| G.189 | 10 | 1.2 | 5.1 | 21.9 | 66.6 | 37 | 4.6 | 0 | 643 | 77 | .... |
| G.190 | 15 | 1.3 | 2.8 | 15.4 | 71.3 | 38 | 6.1 | 0 | 2250 | 4188 | 7250 |
| G.191 | 20 | 0.9 | 2.7 | 15.2 | 74.4 | 38 | 6.4 | 0 | 2540 | 600 | .... |
| G.192 | 25 | 0.9 | 2.5 | 17.7 | 71.2 | 37 | 7.4 | tr. | 2420 | 480 | .... |
| G.193 | 30 | 0.6 | 5.4 | 20.5 | 63.9 | 34 | 7.5 | 0.14 | 2710 | 416 | .... |
| G.194 | 35 | 0.6 | 9.6 | 26.4 | 55.4 | 31 | 7.7 | 5.00 | 2460 | 46 | .... |
| G.195 | 40 | 0.4 | 9.0 | 30.2 | 56.5 | 32 | 7.7 | 0.60 | 2460 | 344 | 3130 |
| G.196 | 45 | 0.3 | 1.2 | 22.3 | 66.2 | 34 | 7.9 | 1.40 | 1802 | 33 | .... |
| G.197 | 50 | 5.5 | | .... | .... | 33 | 8.0 | 1.86 | 1800 | 70 | .... |
| G.198 | 60–65 | 5.5 | | .... | .... | 31 | 8.1 | 1.58 | 1860 | 101 | .... |
| G.199 | 70 | 5.4 | | .... | .... | 34 | 8.1 | 1.39 | 2080 | 55 | .... |
| G.200 | 75 | 0.6 | 2.0 | 21.1 | 63.3 | 32 | 8.2 | 1.40 | 1649 | 75 | 1890 |

' Truog's method.

## Phosphate

The available phosphate content, as measured by the Truog method, is very low in the soil but shows zones of marked accumulation in the lower horizons, especially at 10 to 15 feet where the reaction changes abruptly from highly acid (pH 4.6) to slightly acid (pH 6.1).

The amount of available phosphate in any particular horizon is correlated with the total phosphate content. The kind of phosphate first to be precipitated may be dicalcium phosphate said to be insoluble at reactions more alkaline than pH 6.0. At still higher reaction values, tricalcium phosphate may chiefly comprise the accumulation, and at reactions above pH 7.0 hydroxyapatite may be precipitated. This is probably the main component of the phosphatic accumulation in the 35–40-foot transition layer having a pH of 7.7, occurring immediately below the zone of carbonate accumulation

*Exchangeable bases*

The exchangeable bases of representative layers of the soil are shown in table 2. The total base-exchange capacity is highest in the top 5 feet, but below this to the lowest horizon at 75 feet there is little variation. A notable feature is the fact that leaching to pH 4.6 has not affected the content of exchangeable magnesium. Its high value is maintained throughout the profile, whereas values for calcium, sodium, and potassium have been greatly reduced in the top layer where the bases have been replaced by hydrogen. The total base-exchange capacity is closely correlated with the moisture content at sticky point ($r = 0.91$; significant for $P = 0.05$).

### TABLE 2

*Base-exchange status of soil samples*

(Milligram-equivalents per 100 gm.)

|  | G.188 0–5 FT. | G.189 5–10 FT. | G.195 35–40 FT. | G.196 40–45 FT. | G.200 70–75 FT. |
|---|---|---|---|---|---|
|  | pH 4.6 | pH 4.6 | pH 7.5 | pH 8.0 | pH 8.2 |
| Exchange capacity*...... | 34.4 | 29.2 | 26.4 | 27.6 | 24.4 |
| *Exchangeable bases* |  |  |  |  |  |
| Ca†.................. | 1.5 | 2.4 | 11.3 | 7.7 | 7.9 |
| Mg†.................. | 13.5 | 14.6 | 9.8 | 14.2 | 15.0 |
| Na‡.................. | 1.6 | 2.1 | 3.1 | 5.2 | 6.1 |
| K‡.................. | 0.3 | 0.5 | 0.5 | 0.8 | 0.8 |
| H§.................. | 18.1 | 10.4 | 2.1 | 0.0 | 0.0 |

* By summation of bases and correction for soluble salts (sulfates and chlorides).

† By NaCl leaching, after washing with dilute alcohol until nearly free from sulfate, except for G.200, which was not washed.

‡ By 0.5 $N$ acetic acid leaching; Na values corrected for soluble chloride.

§ By Crowther and Basu's method.

### BULK CHEMICAL COMPOSITION

In tables 3 and 4 are presented the bulk chemical analyses of the whole material and of the clay fraction ( $< 2 \mu$) for the five selected horizons, and in table 5 is given the analysis of sand plus silt, computed from tables 3 and 4. Except for the presence of an excessive amount of free silica in the form of quartz in the top layer, the whole material (table 3) shows little variation in its major components throughout the entire depth of the profile, as is clearly indicated by the constant molecular ratios.

The higher combined silica-alumina ratios are given by the clay fraction with correspondingly lower ratios for the coarser fractions. These last ratio values are not absolutely reliable, however, because of the uncertainty of the "quartz" determination in the clay. In its finely divided state the clay is more liable to attack by chemical reagents, thus increasing the apparent ·content of combined

silica. Indeed, check analysis of the residue, sand plus silt, of the deepest horizon (G.200) gave a silica-alumina ratio of 2.54, whereas that obtained by difference in table 5 is 1.93. The total silica-alumina ratio for the sand plus silt fraction was not materially different, however, when directly determined by analysis, from the derived value given in table 5, thus confirming the view that the error lies in the estimation of the quartz. Further proof may be found in the remarkably constant value of the total silica-alumina ratio of the clay. It

TABLE 3

*Bulk chemical composition of whole material*

|  | G.188 0–5 FT. | G.189 5–10 FT. | G.195 35–40 FT. | G.196 40–45 FT. | G.200 70–75 FT. |
|---|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| $H_2O$ | 6.16 | 7.42 | 7.72 | 9.77 | 9.58 |
| Quartz | 37.76 | 22.00 | 21.43 | 16.52 | 20.64 |
| $SiO_2$ (combined) | 26.80 | 35.35 | 32.30 | 33.87 | 32.35 |
| $Al_2O_3$ | 18.11 | 22.82 | 21.25 | 23.66 | 21.94 |
| $Fe_2O_3$ | 7.75 | 8.47 | 8.78 | 7.36 | 6.73 |
| $TiO_2$ | 0.94 | 0.87 | 0.86 | 0.89 | 0.87 |
| CaO | 0.12 | 0.19 | 0.97 | 1.01 | 0.92 |
| $CaCO_3$ | 0.00 | 0.00 | 0.60 | 1.40 | 1.40 |
| MgO | 1.01 | 1.68 | 1.86 | 2.36 | 2.01 |
| $K_2O$ | 1.31 | 1.95 | 2.08 | 1.78 | 1.88 |
| $Na_2O$ | 0.21 | 0.35 | 0.52 | 0.45 | 0.61 |
| $SO_3$ | 0.06 | 0.10 | 0.88 | 0.28 | 0.22 |
| S | 0.00 | 0.04 | 0.00 | 0.51 | 1.32 |
| Cl | 0.03 | 0.04 | 0.04 | 0.05 | 0.06 |
| *Molecular ratios* |  |  |  |  |  |
| Combined $SiO_2/Al_2O_3$ | 2.51 | 2.63 | 2.58 | 2.43 | 2.51 |
| Combined $SiO_2/R_2O_3$ | 1.98 | 2.12 | 2.05 | 2.03 | 2.10 |
| Combined $SiO_2/Fe_2O_3$ | 9.00 | 11.11 | 9.85 | 12.26 | 12.74 |
| Total $SiO_2/Al_2O_3$ | 6.04 | 4.26 | 4.30 | 3.61 | 4.10 |
| Total $SiO_2/R_2O_3$ | 4.75 | 3.44 | 3.40 | 3.02 | 3.43 |
| Total $SiO_2/Fe_2O_3$ | 22.42 | 18.04 | 16.31 | 18.26 | 20.97 |

is therefore reasonable to conclude that the clay fraction (which forms the major component of the whole material) is very largely, if not entirely, made up of the same or similar minerals to the full depth of the 75-foot profile.

Turning now to the basic constituents, calcium, magnesium, potassium, and sodium, we note that the first obvious feature is the high degree of leaching which each of these, especially calcium, has suffered in the top 10 feet of the profile. Calculations based on carbonate and sulfate determinations prove

that all the lime, except the small amount held in exchangeable form and as phosphate, occurs as calcium carbonate and gypsum. The mode of occurrence of the magnesia is not so easily ascertained. Undoubtedly it is an actual constituent of the clay (being only partly exchangeable) and its partial removal from the topmost layer as compared with the lower layers has evidently not greatly influenced the clay composition. Potassium content of the whole material and of the clay fraction shows a similar trend, but there is a tendency for potassium to increase in the layers above the 40–45-foot layer and to de-

TABLE 4

*Bulk chemical composition of clay fraction (< 2μ)*

|  | G.188 0–5 FT. | G.189 5–10 FT. | G.195 35–40 FT. | G.196 40–45 FT. | G.200 70–75 FT. |
|---|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| $H_2O$.................... | 9.48 | 10.73 | 8.93 | 10.13 | 10.32 |
| Quartz.................. | 11.08 | 7.30 | 8.67 | 6.21 | 7.08 |
| $SiO_2$ (combined)........ | 40.50 | 42.70 | 40.25 | 46.25 | 43.42 |
| $Al_2O_3$.................. | 27.23 | 26.38 | 26.32 | 27.75 | 26.76 |
| $Fe_2O_3$.................. | 7.36 | 7.23 | 9.47 | 5.57 | 5.28 |
| $TiO_2$.................. | 0.95 | 0.82 | 0.89 | 0.91 | 0.79 |
| CaO.................... | 0.00 | 0.00 | 0.00 | 0.25 | 0.26 |
| MgO.................... | 1.19 | 1.69 | 1.80 | 1.78 | 1.82 |
| $K_2O$.................... | 1.89 | 2.52 | 2.42 | 2.14 | 1.65 |
| $Na_2O$.................. | 0.24 | 0.28 | 0.33 | 0.12 | 0.15 |
| *Molecular ratios* |  |  |  |  |  |
| Combined $SiO_2/Al_2O_3$.......... | 2.53 | 2.74 | 2.60 | 2.83 | 2.76 |
| Combined $SiO_2/R_2O_3$.......... | 2.16 | 2.34 | 2.11 | 2.50 | 2.45 |
| Combined $SiO_2/Fe_2O_3$.......... | 14.66 | 15.78 | 11.36 | 22.00 | 21.93 |
| Total $SiO_2/Al_2O_3$.......... | 3.22 | 3.22 | 3.21 | 3.16 | 3.21 |
| Total $SiO_2/R_2O_3$.......... | 2.74 | 2.74 | 2.57 | 2.84 | 2.85 |
| Total $SiO_2/Fe_2O_3$.......... | 18.66 | 18.50 | 13.80 | 24.90 | 25.48 |

crease in the highly leached topsoil. Sodium, on the other hand, decreases in the whole material when traced upward in the profile but increases upward in the clay fraction of the layers above the 40-foot depth. Sulfur, in combination as sulfide (presumably iron pyrites), is highest in amount in the deepest horizon but diminishes to zero in the 35–40-foot layer, evidently having been oxidized to sulfate.

### PETROGRAPHIC ANALYSIS

In table 6 are presented the results of a petrographic analysis of the sand fraction which indicate the occurrence of coarse clay aggregates possibly of a

chloritic nature although not identified. The extent to which these clay aggregates are dispersed in the finer fractions is difficult to estimate, since, in the presence of sulfide as well as organic matter in the deep-lying horizons, it was impossible to determine the ferrous iron content which might have offered some clue to the problem. The presence of glaucophane, which Milner (5) reports in the Miocene clays of Trinidad, was not proved, except that sodium, which is

TABLE 5

*Bulk chemical composition of sand plus silt*
*(whole soil minus separated clay)*

| | G.188 0–5 FT. | G.189 5–10 FT. | G.195 35–40 FT. | G.196 40–45 FT. | G.200 70–75 FT. |
|---|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| $H_2O$.................... | 3.14 | 3.96 | 6.47 | 9.82 | 8.52 |
| Quartz................. | 61.50 | 35.90 | 36.35 | 29.62 | 38.07 |
| $SiO_2$ (combined)........ | 14.34 | 27.12 | 23.80 | 20.67 | 17.52 |
| $Al_2O_3$.................... | 9.82 | 18.70 | 15.85 | 19.90 | 15.46 |
| $Fe_2O_3$................... | 8.05 | 9.45 | 8.15 | 9.84 | 8.55 |
| $TiO_2$.................... | 0.93 | 0.90 | 0.84 | 0.92 | 0.96 |
| CaO.................... | 0.23 | 0.37 | 2.09 | 1.97 | 1.77 |
| MgO.................... | 0.85 | 1.63 | 1.96 | 3.16 | 2.25 |
| $K_2O$.................... | 0.78 | 1.33 | 1.73 | 1.44 | 2.15 |
| $Na_2O$.................... | 0.19 | 0.41 | 0.76 | 0.87 | 1.19 |
| $SO_3$.................... | 0.12 | 0.20 | 1.90 | 0.63 | 0.50 |
| S........................ | ..... | ..... | ..... | 1.14 | 3.02 |
| *Molecular ratios* | | | | | |
| Combined | | | | | |
| $SiO_2/Al_2O_3$.......... | 2.47 | 2.46 | 2.55 | 1.76 | 1.93 |
| Combined | | | | | |
| $SiO_2/R_2O_3$.......... | 1.63 | 1.86 | 1.92 | 1.34 | 1.42 |
| Combined | | | | | |
| $SiO_2/Fe_2O_3$......... | 4.73 | 7.62 | 7.79 | 5.58 | 5.45 |
| Total | | | | | |
| $SiO_2/Al_2O_3$.......... | 13.12 | 5.73 | 6.45 | 4.29 | 6.13 |
| Total | | | | | |
| $SiO_2/R_2O_3$.......... | 8.60 | 4.33 | 4.86 | 3.26 | 4.52 |
| Total | | | | | |
| $SiO_2/Fe_2O_3$......... | 25.10 | 17.72 | 19.68 | 13.62 | 17.36 |

a constituent of the mineral, was found to be relatively high in amount, especially in the deep layers.

## DYE TESTS

The results of dye tests are given in table 7.

*Alizarin absorption* by the ignited material, according to our method for the determination of free (gibbsitic) alumina (2, 3), is small for the whole material as well as for the clay fraction. The combined silt and sand residue (with some clay), remaining after the bulk of the clay was removed, shows definitely higher

values for absorption of this dye.  This implies that *gibbsite* is nearly absent from the clay fraction and that the coarser fractions contain a little of this

### TABLE 6

*Petrographic analysis**

| G.200 70–75 ꜰᴛ. | G.196 40–45 ꜰᴛ. | G.195 35–40 ꜰᴛ. | G.189 5–10 ꜰᴛ. | G.188 0–5 ꜰᴛ. |
|---|---|---|---|---|
| Parent rock | Gray clay | Transition | Soil parent material | Soil |
| | | *Coarse sand* | | |
| Ilmenite bulk. Some quartz, and leucoxene; rare limonite and hematite. Some pyrites. | Abundant fragments of green shale (chloritic?) and clay† with some hematite and limonite; rare leucoxene. | Chiefly limonite. Some white grains which may be gypsum; rare hematite. | Chiefly hematite; considerable portion altered to limonite. Much quartz; rare leucoxene and ilmenite. | Identical with G.189 |
| | | *Fine sand* | | |
| Limonite, quartz, and clay aggregates† | Mainly limonite, quartz, and clay aggregates; some ilmenite and muscovite | Mainly limonite and quartz; some ilmenite, leucoxene, and muscovite | Abundant hematite; some quartz; rare limonite | Chiefly hematite; very little limonite; some quartz and ilmenite |

* By J. C. Griffiths.

† The clay fragments are composite pieces of limonite with some greenish product of unknown identity, possibly a ferrous iron compound.  The clay fractions form aggregates with quartz grains and ferric oxide.

### TABLE 7

*Dye tests*

(Values in dye units absorbed per gram of air-dry material)

| SAMPLE | DESCRIPTION | SAND PLUS SILT | CLAY | WHOLE MATERIAL | | | |
|---|---|---|---|---|---|---|---|
| | | Alizarin uptake | | Janus-red uptake | Diamine sky-blue uptake | | |
| | | | | | Boric | Phosphatic | Difference |
| G.188 | Soil | 18 | 7 | 7 | 835 | 83 | 0 | 83 |
| G.189 | Soil parent material | 20 | 0 | 8 | 960 | .. | .. | .. |
| G.195 | Transition | 21 | 0 | 8 | 1050 | .. | .. | .. |
| G.196 | Gray clay | 26 | 7 | 10 | 920 | .. | .. | .. |
| G.200 | Parent rock | 48 | 12 | 8 | 913 | .. | .. | .. |

secondary "lateritic" component which is evidently present in small amount in the parent rock but largely resists removal during the transformations involved in soil development.

*Janus-red dye absorption* is relatively large for the whole material, and its amount varies little down the profile. Judged by the magnitudes of the dye values previously determined for specific clay minerals (2, 3), the clay mineral present is a highly absorptive kind, such as beidellite.

*Diamine sky-blue absorption* by the soil is negligible in the presence of phosphate, which implies that hydrous ferric oxide is present, since this mineral is "blocked" by phosphate against the uptake of the dyestuff (2, 3). The magnitude of the absorption value indicates that the kind of iron oxide mineral occurring in the soil is one which is highly active and very efficaceous in fixing soluble phosphate, which may be added, for example, as super-phosphate manure.

FIG. I. DEHYDRATION CURVES FOR CLAY FRACTIONS
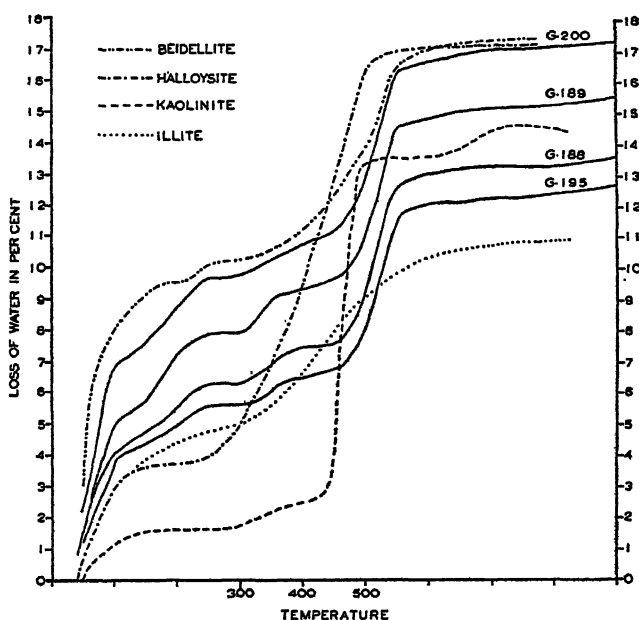


IDENTITY OF COMPONENT CLAY MINERALS

## Dehydration

As an aid to the more exact determination of the component minerals, dehydration curves were obtained for the clay fraction of four of the samples, namely, soil, soil parent material, transition layer, and parent rock, by the method of intermittent drying and weighing of material previously brought to equilibrium in an atmosphere of 50 per cent relative humidity. They are presented in figure 1, in which dehydration curves for kaolinite, halloysite, and beidellite, published by Kelley, Jenny, and Brown (4), and for illite, constructed from data given by Nagelschmidt and Hicks (6) are also plotted for comparison. The curves, unlike the curve for illite, show a distinct break between absorbed

and lattice hydroxyl water, and more closely resemble the curve for beidellite. The results of bulk chemical analysis, however, do not suggest the presence of relatively pure beidellite, and. the conclusion is therefore drawn that the clay consists chiefly of a mixed layer mineral or a mixture of clay minerals, most likely illite and a kaolinic mineral. From the amount of water lost between 450° and 550°, it might be conjectured that the clay consists of approximately 50 per cent kaolin and the remainder illite, with some quartz as revealed by chemical analysis.

### X-ray diffraction analysis and differential thermal analysis

In order to confirm the foregoing conclusions, two samples of clay fraction, namely, those of soil parent material and of gray clay from the 40–45-foot

### TABLE 8
*Chemical composition of illite fraction of clay*

|  | G.189 (SOIL PARENT) (5–10 FT.) | G.196 (GRAY CLAY) (40–45 FT.) |
|---|---|---|
|  | *per cent* | *per cent* |
| SiO₂ | 44.75 | 52.40 |
| Al₂O₃ | 17.72 | 11.78 |
| Fe₂O₃ | 16.68 | 15.95 |
| TiO₂ | 1.89 | 2.61 |
| CaO | ..... | 0.72 |
| MgO | 3.90 | 5.10 |
| K₂O | 5.82 | 6.13 |
| Na₂O | 0.65 | 0.34 |
| H₂O | 8.60 | 4.96 |
| *Molecular ratios:* SiO₂/Al₂O₃ | 4.28 | 7.52 |
| SiO₂/R₂O₃ | 2.68 | 3.86 |

depth were analyzed.[3]   The following report is based on x-ray diffraction and differential thermal analyses.

Sample G.189 (soil parent material at 5–10-foot depth) is composed primarily of kaolinite and illite with kaolinite making up about 50 per cent of the sample. In addition there is a very small amount of montmorillonite. Some quartz is present also and it is present in particles generally smaller than about 1 μ.

Sample G.198 (gray clay at 40–45 foot depth) is composed of the same minerals as the preceding sample. Kaolinite, however, comprises about 60 per cent of the total material and the montmorillonite content is a trifle greater.

### Composition of the "illite" of the clay fractions

If the approximate quantities of kaolinite as determined by analysis are assumed to comprise a mineral of ideal composition, the very small amount of montmorillonite found is neglected, and correction is made for quartz as de-

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[3] By Ralph E. Grim, of Illinois, for whose kind help and cooperation the authors acknowledge their indebtedness.

termined by chemical analysis, the approximate chemical composition of the illite may be calculated. The result is presented in table 8.

The composition thus arrived at for the illite component resembles most of the published analyses (6) chiefly with respect to its potash content in both horizons. The relative proportion of silica to alumina is markedly different, however, as also is the high content of iron oxide.

<div align="center">IDENTITY OF ACCESSORY MINERALS</div>

The whole material, according to the results of bulk chemical analysis, evidently contains certain accessory minerals in addition to quartz. The identity of these extra minerals may best be gauged by a consideration of the analytical data for the sand plus silt fraction given in table 5. The calcium oxide content of the geological parent material and of the transitional layers cannot be fully accounted for by their contents of carbonate, phosphate, and gypsum. Titania is present as ilmenite, which also accounts for some of the ferric oxide, though it should be noted that the illite mineral of the clay contains a relatively large amount of titania and iron oxide also. Soda is evidently associated with the coarser fractions, being more than 1 per cent of the sand plus silt fraction of the geological parent shaley clay. Sodium is most likely a constituent of the mineral forming the "clay aggregates" which are part of the sand fraction of the deeper horizons. In the soil parent material (G.189) where these aggregates have disappeared, the soda content is relatively low and is not much different in the various grain-size fractions. Milner (5) reports that glaucophane is a mineral occurring in the Miocene clays of Trinidad, but its occurrence was not proved in this case and it is doubtful that this mineral is responsible for all the soda found.

Table 9 gives the chemical composition of the sand plus silt after correction for quartz, gypsum, calcium carbonate, and iron pyrites and free iron oxide in G.189. Muscovite was identified microscopically in the sand fraction of sample G.196 but not in that of sample G.189, although the potash content was about the same in both. On the basis of the theoretical potash content for muscovite only 17 per cent of the residue could thus be accounted for, but it might be presumed that the main bulk of the component mineral is chloritic and related to hydrous mica.

Table 10 presents the approximate mineralogical composition of the whole material of the five horizons analyzed, based on the assumption that the clay fractions are similar to those of samples G.189 and G.196, and that in the sand plus silt fractions there is little or no kaolinite or illite, the potash-bearing mineral in the latter fractions being considered as "chloritic."

<div align="center">WEATHERING OF PARENT ROCK</div>

The data presented in table 4 indicate that the amount of combined silica is remarkably constant relative to alumina. This implies great stability of the characteristic clay mineral, and weathering in this particular clay profile thus seems to have affected chiefly the accessory minerals.

The significantly lower value for total potash, both for the whole material and the clay fraction in the soil layer as compared with the soil parent material and the parent rock, may be accounted for by the almost complete decomposition of the "chlorite." It may, however, also indicate slight decomposition of the illite component. Similarly, the definitely higher content of potash in the layers below the top 5 feet of soil as compared with the parent rock indicates a slight accumulation and fixation in nonexchangeable form of potash liberated in the

TABLE 9

*Chemical composition of "chlorite" mineral of sand plus silt fraction*

|  | G.189 (SOIL PARENT) (5–10 FT.) | G.196 (GRAY CLAY) (40–45 FT.) |
|---|---|---|
|  | *per cent* | *per cent* |
| $H_2O$ | 6.20 | 14.70 |
| $SiO_2$ | 42.65 | 31.00 |
| $Al_2O_3$ | 29.32 | 29.82 |
| $Fe_2O_3$ | 14.82 | 12.62 |
| $TiO_2$ | 1.40 | 1.38 |
| $CaO$ | 0.36 | 2.28 |
| $MgO$ | 2.56 | 4.73 |
| $K_2O$ | 2.09 | 2.16 |
| $Na_2O$ | 0.64 | 1.30 |

TABLE 10

*Approximate mineralogical composition of whole soil*

|  | G.188 0–5 FT. | G.189 5–10 FT. | G.195 35–40 FT. | G.196 40–45 FT. | G.200 70–75 FT. |
|---|---|---|---|---|---|
|  | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Quartz | 37.8 | 22.0 | 21.4 | 16.5 | 20.6 |
| Kaolinite | 36.0 | 31.2 | 26.7 | 36.2 | 39.8 |
| Illite | 22.7 | 30.5 | 24.9 | 25.8 | 19.0 |
| Calcium carbonate | .... | .... | 0.6 | 1.4 | 1.4 |
| Calcium phosphate | .... | .... | 0.7 | 0.4 | 0.4 |
| Gypsum | 0.1 | 0.2 | 1.9 | 0.6 | 0.5 |
| Iron pyrites | .... | .... | .... | 1.0 | 2.5 |
| Limonite-hematite | 3.0 | 2.0 | 3.0 | 1.0 | 1.0 |
| Chlorite (?) | 0.4 | 14.1 | 20.8 | 17.1 | 14.8 |

soil and leached downward from the zone of maximum weathering and podzolization. It is known that potash fixation may take place in soils that have been continuously treated, for example, with potassic manures, and that the process is accompanied by the formation of new secondary clay minerals, presumably members of the illite group, from a pre-existing mineral of the montmorillonite-beidellite group (8). Thus the transformation of one type of mineral into the other is a reversible process and depends on the prevailing environmental circumstances.

## TRANSFORMATIONS OF FERRIFEROUS MINERALS

The color of the upper part of the soil proper is bright brick-red to crimson, though distinctly mottled in appearance, and is attributed to hematite. The red color gives place to yellow-ocher below 10 feet, attributed to limonite, although crimson speckling is discernible down to 40 feet. Below that depth, the color is gray to black and the iron-bearing components may here mainly comprise ferrous minerals. In order to distinguish between the various kinds of iron compounds, the five samples of the clay fraction, representing the main divisions of the 75-foot profile, were examined by the Truog method for the "removal of free iron oxide, free alumina, and colloid silica," involving treatment with sodium sulfide and oxalic acid solutions (7). The results obtained are given in table 11.

Most of the soluble material of the clay fraction evidently occurs in the transition layer (G.195) in which about 28 per cent of the total iron oxide is soluble in the Truog reagents; this presumably is mainly limonite. In the

### TABLE 11
*Components removed from clay fraction by Truog treatment*

| SAMPLE NUMBER | HORIZON | COMPONENTS REMOVED BY TRUOG TREATMENT | | | ORIGINAL COMPONENTS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SiO₂ | Fe₂O₃ | Al₂O₃ | Quartz | Combined SiO₂ | Total Fe₂O₃ | Combined Al₂O₃ | Gibbsite Al₂O₃ |
| | | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| G.188 | Soil | 0.16 | 1.66 | 0.32 | 11.1 | 40.5 | 7.4 | 27.2 | 0.7 |
| G.189 | Soil parent material | 0.04 | 1.33 | 0.26 | 7.3 | 42.7 | 7.2 | 26.4 | 0.0 |
| G.195 | Transition | 0.22 | 2.67 | 0.53 | 8.7 | 40.2 | 9.5 | 26.3 | 0.0 |
| G.196 | Gray clay | 0.06 | 0.65 | 0.21 | 6.2 | 46.2 | 5.6 | 27.7 | 0.7 |
| G.200 | Parent rock | 0.08 | 0.86 | 0.64 | 7.1 | 43.4 | 5.3 | 26.8 | 1.2 |

parent clay, only 12 to 16 per cent of the iron oxide is soluble, and in the soil and its parent material, 23 and 19 per cent. There is a gain of 3.6 per cent of ferric oxide by the clay fraction of the transition layer which is derived partly from the layers above through eluviation and partly *in situ* by the breakdown and oxidation of iron-bearing accessory minerals of the sand plus silt fraction, mainly comprising pyrites and possibly a chloritic mineral. The amount of hematite which is responsible for the bright red color of the soil is very small. On the assumption that the Truog treatment effects a partition between hematite and limonite, it would appear that the amount of hematite causing redness in the whole material of the soil is less than 6 per cent of the soil mass.

### SOIL FORMATION

According to recent authority (1), the chief soil-forming processes are calcification, podzolization, laterization, salinization, alkalization, their reverse processes, and gleization. Only the second of these, podzolization, seems to

have been involved in the formation of soil from this particular parent clay. Its most marked result has been the complete removal of calcium carbonate from the upper 25 feet of soil, presumably through continued leaching by carbonated ground-water. Most of the leached carbonate has been precipitated between the 30- and 30-foot levels coincident with a change from acid to alkaline conditions. The original parent rock contains only 1.4 per cent of calcium carbonate and therefore does not merit the description calcareous. The zone of lime accumulation marks the beginning of the transition between the yellow-mottled clay and the uniformly dark gray parent rock.

Along with calcium carbonate, it is apparent that phosphate and gypsum, and to a certain degree potash, have also been leached downward. Thus the marked decrease in reaction value within the 10–10-foot layer from pH 4.6 to pH 6.1, representing a 50-fold increase in hydroxyl-ion concentration, and distinguished by red mottling giving place to yellow, is accompanied by a distinct accumulation of calcium phosphate, much of which is soluble in dilute acid (0.002 $N$ $H_2SO_4$; Truog's extracting reagent) and would be regarded as available to plants.

A distinct rise in sulfate content in the 30–40-foot transition layer, coupled with the appearance of gypsum crystals, indicates that calcium sulfate has accumulated in appreciable quantity. Judging by the electrical conductivity values, however, gypsum also occurs in layers above the 35-foot level which were not chemically analyzed and is fairly uniformly distributed between the 10- and the 40-foot depths. In this particular parent rock, gypsum occurs in relatively small amount (estimated at 0.5 per cent). In other examples of red-weathering clays in Trinidad, it may be very plentiful and in extreme cases may amount to over 30 per cent of the weight of the clay.

There seems not to have been any profound leaching or segregation of iron oxides anywhere within the profile, except for a slight accumulation of rusty concretionary limonite in the 20–25-foot layer in the middle of the soil parent material, where the reaction changes from acid to alkaline, and again in the transition layer between soil parent material and parent rock. In the upper soil layer, hematite forms, together with quartz, the bulk of the sand fraction.

### Water relations

Evidently in this profile there has been little or no penetration of water below the 35-foot depth. This therefore approximately marks the lower level of a "perched" water zone, the upper level or water table of which probably coincides frequently with the ground surface during wet weather. That considerable fluctuation in water level occurs within the upper 10 feet of soil is shown by the prevalent crimson mottling, which indicates that profound oxidation and dehydration have occurred. This zone may therefore be regarded as a "zone of intermittent saturation." The "zone of nonsaturation" is probably represented only by a relatively very shallow surface layer of humic soil, crumb soil, and litter, not differentiated in the present investigation. The "zone of permanent saturation" apparently extends from 10 to about 25 feet, forming a moist belt below

which the water content gradually diminishes until, at about 35 feet, the material (upper part of parent rock) is relatively dry. Below this depth, and down to at least 75 feet, the profile is permanently dry.

## Oxygen relations

Judged by the presence and mode of distribution of hematite in the upper part of the profile, aeration in this soil is not particularly good and takes place chiefly, if not solely, along cracks and old root traces. This accounts for the mottled and speckled appearance in the first 10 feet of the profile. Some slight oxidation may be traced downward to considerable depth, but it is confined to the slip surfaces of the original structure-units of the clay between which slow oxygen diffusion may intermittently proceed.

## SUMMARY

This article describes the results of an investigation into the kind and degree of weathering and of soil formation under a humid tropical climate, undulating topography, and forest vegetation, affecting a foraminiferal sedimentary clay or shale of Oligocene age which is widespread in Trinidad. The data are unique in that they apply to samples collected at successive 5-foot depths from an auger boring 75 feet deep. The methods used were the same as those previously employed by the writers in studies of soil genesis from intermediate igneous rocks, namely, bulk chemical analysis of whole materials and clay fractions, microscopical examination of sand fractions, construction of dehydration curves, determination of physical and chemical constants and dye absorption. The clay fractions of two horizons were also submitted to x-ray diffraction examination and to thermal analysis. The following main results were obtained:

The parent rock consists chiefly of kaolinite (40 per cent) and a mineral of the illite group. The mineral next in abundance is quartz (20 per cent). The accessory minerals include aggregates of an unidentified greenish clay mineral presumed to be chlorite. The remainder is made up of iron pyrites, ilmenite or leucoxene, calcium carbonate and phosphate, gibbsite, hematite with limonite, and a small amount of gypsum.

Weathering of the parent rock is confined to the upper 40 feet and has mainly affected the accessory minerals. The illite component shows very little hydrolytic decomposition except in the soil layer (0–5 feet) where slight loss of potash has occurred. This may have been liberated, however, from decomposing muscovite or from the unidentified chlorite mineral. The chief weathering processes have been oxidation and hydration.

Soil formation has solely comprized podzolization, that is, profound leaching by carbonated ground water.

Water penetration in this profile seems not to exceed 35 feet, which marks the base of the zone of accumulation of calcium carbonate.

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# SOME FACTORS INVOLVED IN THE DECARBOXYLATION
## RATE OF URONIC GROUPS OF SOIL ORGANIC
## MATTER AND PECTIN

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Evolution of $CO_2$ from soil organic matter when boiled with 12 per cent hydrochloric acid according to the method of Lefévre and Tollens (4) has been noted by various investigators (1, 7, 8, 9). Though positive identification of uronides in the soil has yet to be demonstrated, it is assumed that the $CO_2$ comes from decarboxylation of uronides, inasmuch as no other carboxyl groups yield more than small quantities of $CO_2$ by this treatment. Such substances as simple sugars and polysaccharides, however, may yield small quantities of $CO_2$ when subjected to the uronic acid determination (2). Quantitative significance cannot be attached to the $CO_2$ liberated from these sources.

A possible means of identifying the presence of uronides, by taking into account the characteristic rate at which the uronides decarboxylate, was first suggested by Norman (6). Later Whistler, Martin, and Harris (10) produced evidence that evolution of $CO_2$ from pure uronic acids takes place at a rapid rate and is complete in a short time, whereas polysaccharides free from uronic units liberate $CO_2$ at a slow rate that remains fairly constant throughout the boiling period. Whether or not the apparent uronides in soils possess the same characteristics as pure polyuronides has not been shown.

The necessity of decarboxylating the apparent uronic constituents in the presence of the great variety of soil substances presents a real opportunity for nonuronic substances to interfere with quantitative and qualitative evaluation of uronic carbon in soils. For this reason it is imperative that the soil be examined for interfering substances and that these substances be eliminated as a possible source of error. Furthermore the optimum conditions for differentiating uronic carbon in soils, by taking into account the decarboxylation rate of the apparent uronic units, must be established. Although both temperature and acid concentration have been shown to influence the rate of decarboxylation of pure polyuronides (1), information about the influence of these factors on the apparent uronides of soils is not available. Should the apparent uronides of soils react similarly to changes in temperature and acid concentration during the uronic determination as do pure polyuronides, another link in the evidence that the $CO_2$ evolved from the soil comes from uronic constituents will be established.

The purpose of this investigation is to determine the extent to which nonuronic soil substances interfere with the rate of $CO_2$ evolution from apparent uronic units

of soil and to compare the influence of various factors on the rate of decarboxylation of pure polyuronides with that of apparent uronic units of soil.

## METHODS AND MATERIALS

The apparatus employed in the uronic acid determination was essentially the same as that described by Bartholomew and Norman (1) except that an additional set of absorption towers was arranged so that the $CO_2$ evolved during the

TABLE 1

*Surface soils used in uronide studies*

| NAME | DEPTH | NUMBER | LOCATION | SOIL GROUP | DESCRIPTION |
|---|---|---|---|---|---|
| | *inches* | | | | |
| Clarion silt loam | 0-7 | 323501 | LaSueur Co., Minn. | Prairie | Brownish black to black granular friable |
| Gloucester loam | 0-4 | 38434 | Worchester Co., Mass. | Brown podzolic | Dark brown fine sandy loam |
| Carrington loam . | 0-3 | C-2916 | Buchannan Co., Iowa | Gray-brown podzolic | Dark brown granular friable loam |
| Williams stony loam | 1-5 | 471175 | Central Reconnaisance, Mont. | Chestnut | Very dark brown blocky fine cloddy loam |
| Bearden silt clay loam | 0-8 | Kerp-118 | Crookston, Minn. | Gray-brown podzolic | Black granular calcareous silty clay loam |
| Russell silt loam | 0-2 | C-3174 | Morgan Co., Ind. | Gray-brown podzolic | Brownish gray silt loam |
| Houston black clay | 0-12 | Agron-Plot #1 | Bell Co., Tex. | Rendzina | Black crumbly calcareous clay |
| Clinton silt loam | 2½-5½ | 2-1-2-8-118 | Ogle Co., Ill. | Gray-brown podzolic | Light brownish gray to brown-gray silt loam |
| Beaverton loam | 1-4 | 471126x | Central Reconnaisance, Mont. | Brown | Grayish brown fine-grained loam |
| Miami silt loam | 0-8 | 2859260 | St. Joseph Co., Ind. | Gray-brown podzolic | Light brown loose silt loam |
| Dewey silt loam | 0-8 | 403415 | Claiborn Co., Tenn. | Red podzolic | Grayish brown silt loam |
| Norfolk sandy loam | 0-6 | 2510042 | Chandler Co., Ga. | Yellow podzolic | Dark grayish brown sandy loam |
| Portneuf silt loam | 0-8 | 541801 | Idaho Falls Area Ida. | Sierozem | Light grayish brown silt loam |
| Mohave sandy clayloam | 0-10 | 5118116 | Sulfur Springs Valley, Ariz. | Red desert | Dull reddish brown cloddy sandy clay loam |
| Leetonia (mor) | ½-0 | 46445 | Big Savage Mt., Md. | Podzol | Brownish black mor (A₀) |
| Leetonia sandy loam | ½-0 | 46450 | Big Savage Mt., Md. | Podzol | Grayish black silt loam (A₁) |

decarboxylation process could be shifted from one absorption tower to another at will. This enabled measurement of the rate of $CO_2$ evolution at any time during the decarboxylation process and, in addition, measurement of the total quantity of $CO_2$ liberated. The quantity of $CO_2$ evolved was determined every 15 minutes for the first hour and thereafter at the end of ½-, 1-, 2½-, and 2-hour periods to give a cumulative total of 7 hours. Boiling usually took place 15 to 16 minutes after heating began. Carbon from the evolved $CO_2$ is referred to as

evolved C. The uronic C = evolved C × 6, and the uronic anhydride = evolved C × 14.67.

The apparent uronic carbon of soil organic matter was determined on 30-gm. samples of soil after vigorous aeration in 150 ml. of 12 per cent hydrochloric acid with $CO_2$-free air for 18 hours. Surface and subsurface soils representative of the great soil groups were selected for the study (tables 1 and 2).

TABLE 2

*Subsurface soi s used in uronide studies*

| NAME | DEPTH | NUMBER | LOCATION | SOIL GROUP | DESCRIPTION |
|---|---|---|---|---|---|
| | *inches* | | | | |
| Clarion | 20–30 | 323504 | LaSueur Co., Minn. | Prairie | B₂ horizon, dark yellowish brown silty clay loam |
| Gloucester | 14–25 | 38436 | Worchester Co., Mass. | Brown podzolic | B₁ horizon, brown loam, brownish to olive-yellow |
| Carrington | 22–40 | C-2919 | Buchannan Co., Iowa | Gray-brown podzolic | B₁ horizon, brown loam, fine sandy loam |
| Russell | 23–26 | C-3178 | Morgan Co., Ind. | Gray-brown podzolic | B₂ horizon, dark yellowish brown to medium brown silty clay |
| Clinton | 23¼–27½ | 2-1-2-8-124 | Ogle Co., Ill. | Gray-brown podzolic | B₁ horizon, dark yellowish brown to medium brown silty clay |
| Miami | 18–28 | 2859262 | St. Joseph Co., Ind. | Gray-brown podzolic | B₂ horizon, dark yellowish brown to medium brown silty clay loam |
| Dewey | 18–42 | 403417 | Claiborn Co., Tenn. | Red podzolic | B₂ horizon, brownish red silty clay |
| Norfolk | 16–30 | 2510044 | Chandler Co., Ga. | Yellow podzolic | B₁, horizon, brownish yellow sandy clay loam |
| Leetonia | 1–3 | 46447 | Big Savage Mt., Md. | Podzol | B₋₁, and B₋₂ horizons |
| | 13–20 | 46448 | | | |

Lemon pectin was used in this investigation, as were phenolic acids from redwood bark.[2] This redwood lignin from cook 5 is reported by Lewis *et al.* (5) to contain the following groups:

|  | per cent |
|---|---|
| Methoxy | 2.7 |
| Carboxyl | 4.4 |
| Phenolic | 7.8 |
| Alcoholic | 2.1 |

### REPRODUCIBILITY OF RESULTS

To gain some information regarding the accuracy that may be expected by the method adopted for uronic determination, 10 virgin soil samples from the Mandan, North Dakota, plots were selected, and the apparent uronic carboxyl carbon was determined on duplicate 30-gm. portions. The organic carbon, clay, and apparent uronic carbon contents are reported in table 3. Results of apparent

[2] Supplied through courtesy of Institute of Paper Chemistry, Appleton, Wisconsin.

uronic carbon analysis clearly show that the method adopted reproduced results with reasonable degree of accuracy. The standard error of mean of duplicate samples is 0.065 mgm. of uronic carbon where the amount of carbon evolved from the different soils ranged between 4.5 and 6.3 mgm. Moreover, the percentage

TABLE 3

*Apparent uronic carbon in Cheyenne fine sandy loam surface soil*

| SOIL NUMBER | C EVOLVED* | $\dfrac{\text{C EVOLVED}}{\text{ORGANIC C}}$ | $\dfrac{\text{URONIC C}}{\text{ORGANIC C}}$ | ORGANIC CARBON IN SOIL | CLAY |
|---|---|---|---|---|---|
| | *mgm.* | *per cent* | *per cent* | *per cent* | • *per cent* |
| 441 | 4.55 | 2.84 | 17.0 | 1.60 | 11.1 |
| A | 4.51 | 2.82 | 16.9 | | |
| 444 | 5.06 | 2.52 | 15.1 | 2.01 | 12.0 |
| B | 5.05 | 2.51 | 15.1 | | |
| 447 | 5.73 | 2.32 | 13.9 | 2.47 | 13.7 |
| C | 5.77 | 2.34 | 14.0 | | |
| 450 | 5.63 | 2.46 | 14.8 | 2.29 | 14.6 |
| D | 5.65 | 2.47 | 14.8 | | |
| 453 | 4.71 | 2.52 | 15.1 | 1.87 | 12.3 |
| E | 4.47 | 2.39 | 14.3 | | |
| 456 | 5.67 | 2.50 | 15.0 | 2.27 | 13.9 |
| F | 5.47 | 2.41 | 14.5 | | |
| 459 | 5.30 | 2.54 | 15.2 | 2.09 | 13.7 |
| G | 5.32 | 2.55 | 15.3 | | |
| 462 | 4.89 | 2.63 | 15.8 | 1.86 | 13.3 |
| H | 5.01 | 2.69 | 16.1 | | |
| 465 | 6.29 | 2.16 | 13.0 | 2.91 | 14.7 |
| I | 6.16 | 2.12 | 12.7 | | |
| 468 | 5.61 | 2.35 | 14.1 | 2.39 | 15.8 |
| J | 5.43 | 2.27 | 13.6 | | |

* Analysis of error between duplicate samples shows the following: $S = 0.095, S\bar{x} = 0.065$, and the 95 per cent fiducial limits of means of two samples is ± 0.145 mgm. of carbon.

of organic carbon that was uronic in nature did not vary greatly, though the total carbon content of the soils varied as much as twofold. There was no general correlation between clay content and proportion of uronic carbon to total carbon.

POSSIBLE SOURCES OF ERROR

*Carbonates*

Presence of carbonates in the soil resulted in rapid liberation of $CO_2$ upon addition of the hydrochloric acid used for the uronic determination. Some of the $CO_2$

remained absorbed in the soil-acid system even at the high acid concentration of 12 per cent and could be removed only after extensive aeration of the solution with $CO_2$-free air. Data in table 4 show that, even after aeration of Houston

TABLE 4

*Carbon evolved from soil treated with boiling 12 per cent HCl*

| SOIL | DEPTH | pH | CARBON EVOLVED PER GRAM TOTAL ORGANIC CARBON | | | | | INOR-GANIC CARBON | ORGANIC CARBON | $\frac{\text{URONIC C}}{\text{ORGANIC C}}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | No Pre-treat-ment | Treated at room temperature | | | | | | |
| | | | | Aerated with $CO_2$-Free Air | | | Not Aerated | | | |
| | | | | 1 Hour | 4 Hours | 18 Hours | 18 Hours | | | |
| | *inches* | | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *per cent* | *per cent* | *per cent* |
| *Surface horizons* | | | | | | | | | | |
| Clarion silt loam...... | 0–7 | 7.1 | 23.4 | 20.2 | 20.5 | 20.6 | 22.1 | 0 | 4.28 | 12.4 |
| Gloucester loam....... | 0–4 | 5.2 | 24.5 | 24.5 | 24.0 | 24.1 | 25.9 | 0 | 4.06 | 14.5 |
| Carrington loam...... | 0–3 | 5.5 | .... | .... | 24.3 | 24.3 | .... | 0 | 3.95 | 14.6 |
| Williams stony loam.. | 1–5 | 6.9 | 26.6 | 26.1 | 25.0 | 24.8 | 27.5 | 0 | 3.80 | 14.9 |
| Bearden silt clay loam............. | 0–8 | 8.1 | 31.4 | 23.7 | 22.4 | 19.7 | 31.3 | 15.9 | 3.58 | 11.8 |
| Russell silt loam...... | 0–2 | 5.5 | .... | .... | .... | 26.0 | .... | 0 | 3.15 | 15.6 |
| Houston black clay... | 0–12 | 7.6 | 40.4 | 24.6 | 24.5 | 19.6 | 33.5 | 12.7 | 1.95 | 11.8 |
| Clinton silt loam...... | 2½–5½ | 5.4 | 48.8 | 31.2 | 24.2 | 24.5 | 32.4 | 0 | 1.95 | 14.7 |
| Beaverton loam....... | 1–4 | 7.7 | 55.5 | 37.6 | 34.5 | 34.1 | 49.5 | 0 | 1.88 | 20.5 |
| Miami silt loam....... | 0–8 | 5.5 | 34.4 | 30.3 | 30.2 | 30.5 | 31.7 | 0 | 1.74 | 18.3 |
| Dewey silt loam....... | 0–8 | 6.6 | 53.5 | 47.4 | 38.7 | 38.0 | 52.8 | 0 | 1.12 | 22.8 |
| Portneuf silt loam..... | 0–8 | 7.7 | 39.0 | 32.7 | 32.7 | 32.7 | 35.2 | 0 | 0.84 | 19.6 |
| Mohave sandy clay loam............... | 0–10 | 7.0 | 29.3 | 27.5 | 26.9 | 26.7 | 29.3 | 0 | 0.44 | 16.0 |
| *Subsurface* | | | | | | | | | | |
| Clarion.............. | 20–30 | 6.3 | 45.5 | 43.4 | 37.4 | 37.0 | 39.2 | 0 | 0.93 | 22.2 |
| Gloucester.......... | 14–25 | 4.2 | 37.3 | 37.1 | 33.2 | 33.3 | 37.1 | 0 | 0.40 | 19.2 |
| Carrington.......... | 22–40 | 5.1 | 54.8 | .... | .... | 42.0 | .... | 0 | 0.41 | 25.2 |
| Russell.............. | 23–26 | 5.0 | 41.9 | .... | .... | 32.0 | .... | 0 | 0.34 | 20.0 |
| Clinton.............. | 23½–27½ | 4.9 | 48.8 | 34.3 | 32.0 | 31.0 | 46.9 | 0 | 0.26 | 18.6 |
| Miami.............. | 18–28 | 4.4 | 42.3 | 39.0 | 33.4 | 33.4 | 36.4 | 0 | 0.31 | 20.0 |
| Dewey.............. | 18–42* | ... | .... | .... | .... | .... | .... | 0 | 0.30 | .... |
| Norfolk.............. | 16–30 | 5.1 | 50.6 | 49.4 | 49.5 | 50.0 | 52.1 | 0 | 0.30 | 30.1 |

* High concentration of manganese oxides in subsurface interfered with $CO_2$ measurements.

clay for an hour, as much as 25 per cent of the carbon evolved during the uronic analysis was carbonate carbon. Aeration at room temperature longer than 18 hours failed to change the amount of carbon liberated during the uronic determination; thus it was assumed that after 18 hours' aeration the carbon evolved did not come from carbonates.

### Absorbed carbon dioxide

A certain amount of $CO_2$ is usually held to soil by absorptive forces. This is liberated concurrently with the uronic $CO_2$, from which it cannot be distinguished. Inasmuch as the total amount of uronic carboxyl carbon in soil is small (see table 4), the amount of absorbed $CO_2$ often may constitute an appreciable amount of the total evolved. Data in table 4 show that soils such as Clinton silt loam ($2\frac{1}{2}$ to $5\frac{1}{2}$ inches) may liberate twice as much carbon as is contained in the uronic carboxyl groups when not aerated to free the absorbed $CO_2$. It appears that much less $CO_2$ is absorbed on acid soils than on more nearly neutral soils. Usually an hour of aeration removed most of the absorbed $CO_2$ when no carbonates were present. All the absorbed $CO_2$ apparently was removed after 4 hours of aeration, for additional aeration failed to reduce the total yield during the uronic determination.

### Manganese oxides

The presence of manganese dioxide and other manganese oxides in Dewey silt loam subsurface caused free chlorine to be liberated when heated with 12 per cent hydrochloric acid solution. Since the liberated chlorine reacted with the base solution that was used to collect $CO_2$ from uronic groups, either traps sufficient to collect the chlorine would have to be installed or a gravimetric procedure would need to be adopted to measure properly the uronic carbon when oxides of manganese are present in appreciable amounts.

### Organic acids

Although only the uronic carboxyl group has been shown to be completely decarboxylated by the uronic determination, some types of organic acids have been shown to liberate small amounts of $CO_2$. The presence of hydroxy and phenolic acid complexes in soil organic matter (3) makes it most urgent to examine the possibility of $CO_2$ evolution from these sources.

Table 5 shows that the quantity of carbon liberated from salicylic, gallic, ellagic, and $p$-hydroxy-benzoic acids and phenolic acids from redwood bark amounted to 0.3 per cent or less of the total carbon in the organic acids.

#### FACTORS INFLUENCING DECARBOXYLATION RATE

Since the rate of decarboxylation of the uronic units may prove useful in distinguishing between uronic-bearing compounds from different sources, it would be expedient to adopt conditions of decarboxylation that prove most favorable for its accomplishment and rigidly to standardize the most promising set of conditions, thus holding constant any error introduced by nonuronic sources. Comparisons of response of soil and pure polyuronide to variations in conditions of digestion may also furnish additional information as to the nature of the $CO_2$-yielding constituents of soil organic matter.

### Temperature

The rate of apparent uronic carboxyl carbon evolution from Cheyenne fine sandy loam (nos. 401 and 465) as a result of boiling in 12 per cent hydrochloric

acid at 135° C. and 110° C. is plotted in figures 1 and 2, respectively. The apparent uronic units of soil sample 465 were also decarboxylated at 128° C. The curves were obtained by plotting the calculated milligrams of carbon evolved per

TABLE 5

*Evolution of carbon from some hydroxy and phenolic acids*

| SUBSTANCE* | CARBON | C EVOLVED | $\dfrac{\text{C EVOLVED}}{\text{TOTAL C}}$ |
|---|---|---|---|
| | *per cent* | *mgm.* | *per cent* |
| P-hydroxy-benzoic acid................... | 60.9 | 0.73 | 0.24 |
| Salicylic acid............................. | 60.9 | 0.81 | 0.30 |
| Gallic acid............................... | 47.1 | 0.38 | 0.16 |
| Ellagic acid..............................  | 55.6 | 0.16 | 0.06 |
| Phenolic acids† ......................... | 63.3 | 0.79 | 0.25 |

\* Each sample, 500 mgm.

† From redwood bark.
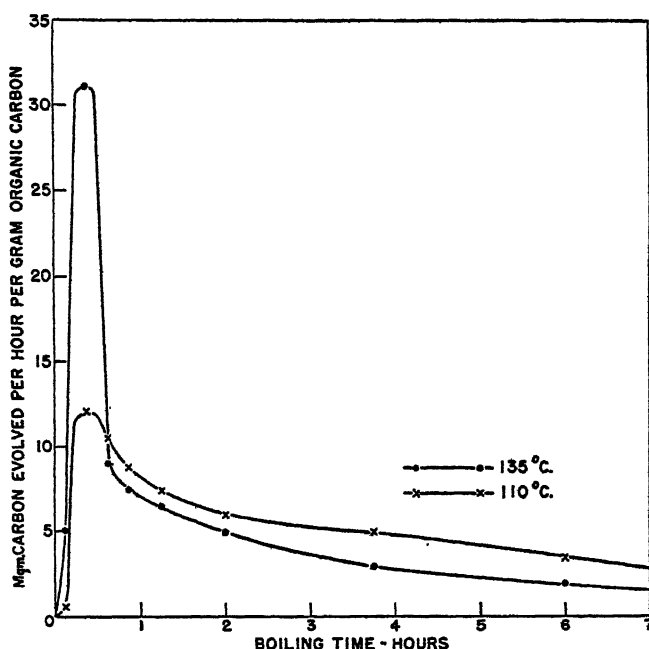


FIG. 1. DECARBOXYLATION RATE OF APPARENT URONIC UNITS OF CHEYENNE FINE SANDY LOAM (NO. 401) AT DIFFERENT TEMPERATURES

hour per gram of organic carbon in the original sample from the mean quantity of $CO_2$ liberated during definite time intervals as follows: 15 minutes of preheating, and $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, $2\frac{1}{2}$, and 2 hours of boiling. Figures obtained by this method have no absolute value. The figures 1 and 2 indicate that a considerable reduction in rate of carbon evolution resulted from lowering the temperature of diges-
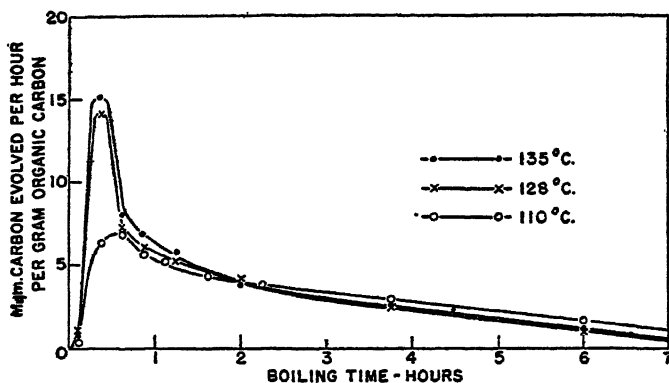
FIG. 2. DECARBOXYLATION RATE OF APPARENT URONIC UNITS OF CHEYENNE FINE
SANDY LOAM (NO. 465) AT DIFFERENT TEMPERATURES
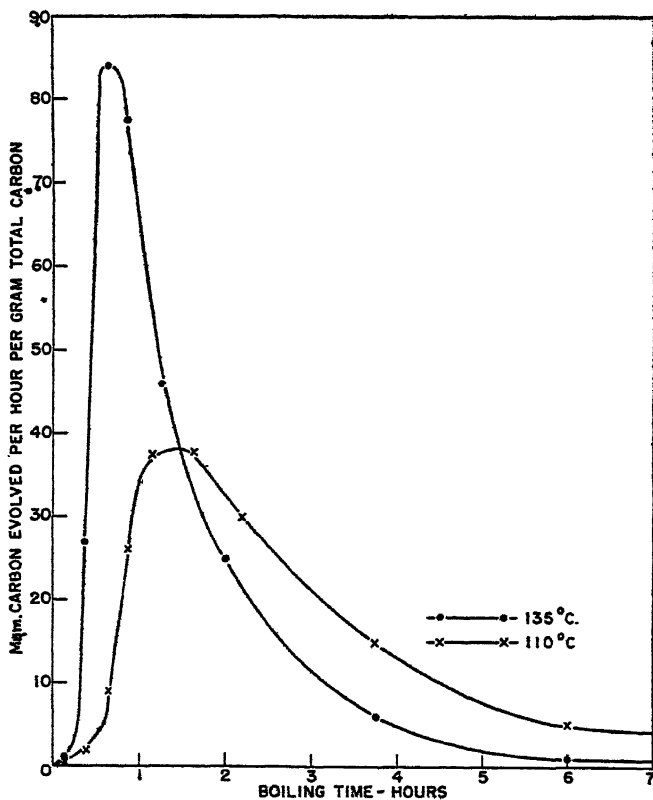


FIG. 3. DECARBOXYLATION RATE OF URONIC UNITS OF LEMON PECTIN
AT DIFFERENT TEMPERATURES

tion from 135° to 110° C. and that at the latter temperature the peak rate of
evolution for soil 465 was delayed about 15 minutes. Moreover, the intensity
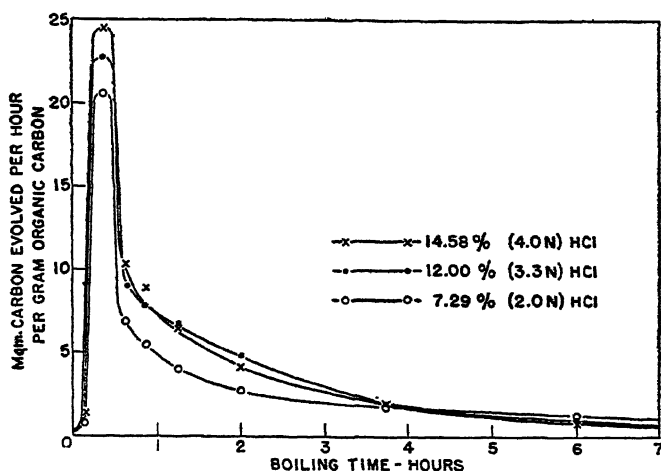
FIG. 4. DECARBOXYLATION RATE OF APPARENT URONIC UNITS OF RUSSELL SILT
LOAM (0–2 INCHES) AT VARIOUS ACID CONCENTRATIONS
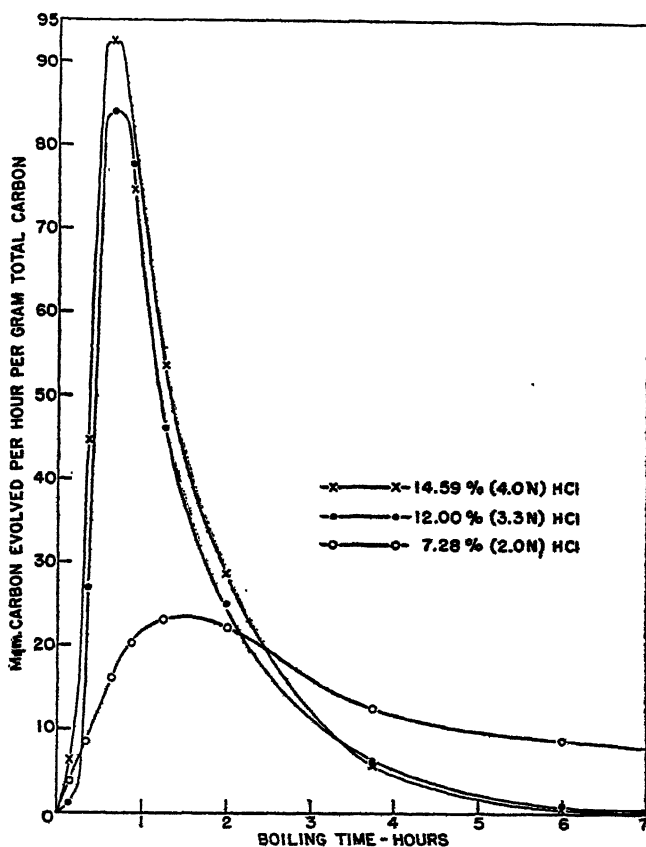


FIG. 5. DECARBOXYLATION RATE OF URONIC UNITS OF LEMON PECTIN
AT VARIOUS ACID CONCENTRATIONS

of the rate at the lowest temperature was considerably reduced during the early stages of heating. Similar treatment of lemon pectin (polygalacturonide) gave similar results (fig. 3).

## Acid concentration

Small changes in acid concentration used in the uronide determination are known to have little influence on the total quantity of uronic carboxyl carbon liberated from pure polyuronides, though there is some evidence that the rate of evolution may be altered. The rate of evolution of carbon from Russell silt
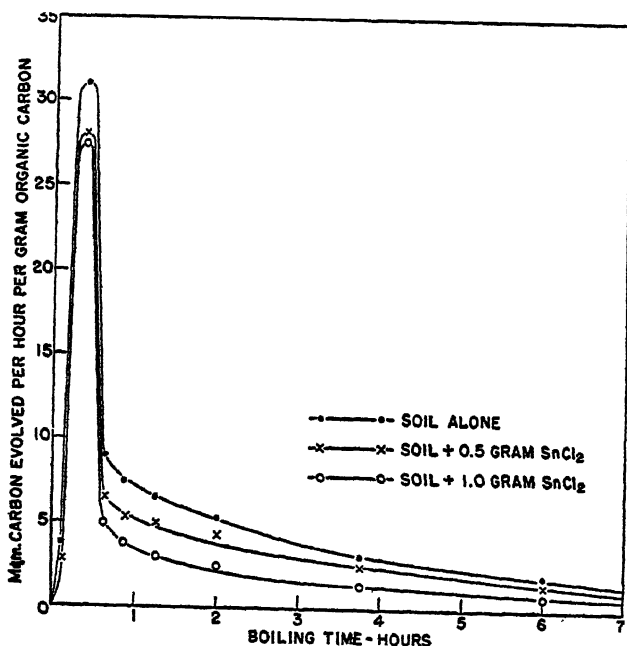


FIG. 6. DECARBOXYLATION RATE OF APPARENT URONIC GROUPS OF CHEYENNE FINE SANDY LOAM (NO. 401) WITH AND WITHOUT SnCl₂

loam (0-2 inches) in 7.28, 12.00 and 14.59 per cent solutions[3] of hydrochloric acid at 135° C. is shown in figure 4. The high initial rate of carbon liberation decreased as the acid concentration was decreased. The total milligrams of carbon evolved per gram of organic carbon was 20.4, 25.9, and 25.8 for the aforementioned acid concentrations, respectively, Lemon pectin evolved 95.6, 116.5, and 124.0 mgm. of carbon per gram total carbon as a result of boiling 7 hours at 135° C. with 7.28-, 12.00- and 14.59 per cent hydrochloric acid solutions, respectively. Figure 5 shows that the rate of decarboxylation of pectin was not greatly different at the two highest acid concentrations. The lowest concentration permitted less intensive rate of decarboxylation during the early stages of boiling.

[3] Correspond to 2.00 $N$, 3.29 $N$, and 4.00 $N$ solutions, respectively.

*Reducing substances*

Additions of reducing substances, such as stannous or ferrous salts or zinc dust, to the acid used in the uronic determination might be expected to reduce the yield of $CO_2$ from uronic carboxyl groups. That this is the case is shown in figure 6. Additions of 0.5 and 1 gm. of stannous chloride to 30 gm. of Cheyenne fine

TABLE 6

*Influence of soil on decarboxylation of uronic units of pectin*

| SOIL | CARBON EVOLVED | | | | |
|---|---|---|---|---|---|
| | 1<br>Soil* Alone | 2<br>Pectin†<br>Alone | 3<br>Pectin and<br>Soil | 3-1<br>Pectin Cal-<br>culated | 3-2<br>Soil Calcu-<br>lated |
| | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* |
| Cheyenne fine sandy loam (No. 401).... | 18.6 | 20.4 | 38.3 | 19.7 | 17.9 |
| Cheyenne fine sandy loam (No. 465).... | 20.2 | 20.4 | 38.9 | 18.7 | 18.5 |
| Clinton silt loam........................ | 17.2 | 20.4 | 36.8 | 19.6 | 16.4 |
| Russell silt loam........................ | 24.5 | 20.4 | 42.6 | 18.1 | 22.2 |

\* 30 gm. soil (oven-dry basis).
† 0.5 gm. lemon pectin (oven-dry basis).
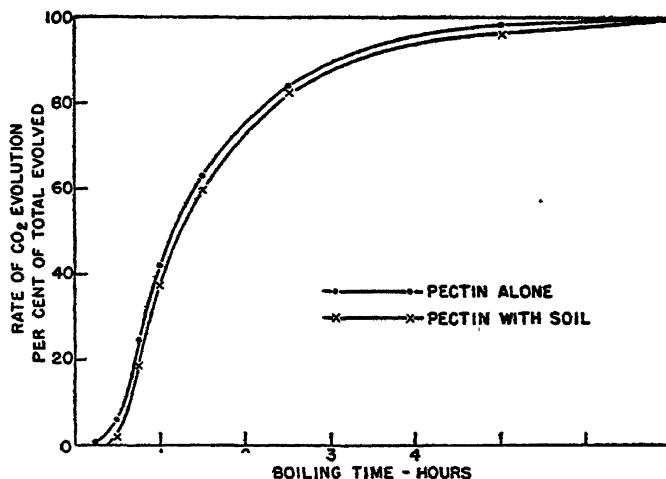


FIG. 7. DECARBOXYLATION RATE OF URONIC UNITS OF PECTIN ALONE AND OF PECTIN IN THE PRESENCE OF RUSSELL SILT LOAM (0-2 INCHES)

*Pectin with soil* represents the difference between the amount of carbon evolved for pectin plus soil and the amount evolved for soil alone.

sandy loam (no. 401) reduced the total quantity of carbon evolved and resulted in uniform lowering of evolution throughout the period of boiling. The largest amount of the stannous salts reduced the rate of evolution the most. Ferrous sulfate and zinc dust had like influence on the rate of carbon evolution from soil organic matter.

*Soil*

Reducing substances or even oxidizing agents in the soil could interfere with the rate and extent of decarboxylation of uronic units. To gain some information about this, uronic determinations were made on 30-gm. surface samples of Cheyenne sandy loam (nos. 401 and 465), Clinton silt loam, and Russell silt loam in the presence of 0.5 gm. of pure pectin. Data in table 6 show that there was no particular influence of the soil on the total amount of carbon evolved from the pectin. The influence of a pure polygalacturonide on the total yield of carbon from apparent uronic units of soil also appears to be within the possibility of experimental error. The rate of decarboxylation of uronic units of pectin was little changed as a result of association with soil (fig. 7).

## DISCUSSION

The uronic determination when applied to soil yielded $CO_2$ in quantities that could be reproduced with considerable degree of accuracy when soil absorbed $CO_2$, carbonates, or large amounts of manganese oxides were absent. Apparently, small amounts of manganese oxides do not cause free chlorine to be liberated, inasmuch as surface soil of Dewey silt loam and many of the other subsurface samples contained small quantities of manganese oxides, yet chlorine was not detected in the silver sulfate traps of the uronic apparatus during the determination.

The presence of absorbed $CO_2$ and carbonates not only resulted in a greater total yield of $CO_2$ than could be accounted for by the apparent uronic groups, but also intensified the rate of evolution during the first 15 minutes after boiling commenced. Since this nonuronic source of $CO_2$ seriously interfered with the shape of the curve showing the rate of decarboxylation of apparent uronic units, carbonates and absorbed $CO_2$ must be removed before the rate curves can be of any help in studies designed to differentiate uronic units from different sources.

Uniformity in the proportion of apparent uronic carbon to organic carbon, though the organic carbon content of the soils varied almost twofold, is a feature of the analysis of the samples from the Mandan plots. Moreover, this proportion was not altered by variations in the clay content. The broad implication is that a given soil may have a uronic carbon/total carbon ratio that remains nearly constant regardless of crop rotation system and slight differences in clay content. It is quite likely, however, that differences in farming practices that do not change the quantity of soil organic matter and uronide content may result in changes in the nature of uronic constituents. This remains to be investigated.

It is not inconceivable and would not be inconsistent with the results obtained that part of the carbon evolved from the soil organic matter came from nonuronic constituents. The proportion probably was not great (1), though it is difficult to estimate. The evolution of small amounts of nonuronic carbon from organic sources should not appreciably alter the shape of the decarboxylation curve, for it has been shown that the rate of $CO_2$ evolution from nonuronic polysaccharides is claimed to be (10) rather slow and relatively uniform.

The similarity in response of $CO_2$-yielding substances of soil organic matter and

that of a pure polyuronide substance as pectin to changes in temperature and in acid concentration during the uronic determination furnished further presumptive evidence of the presence of uronic units in soil. It also appears significant that soil free from carbonates, absorbed $CO_2$, and manganese oxides or large quantities of reducing substances contained no substance that interfered with the normal decarboxylation of uronic units from a pure polyuronide of known constitution. It was also hoped that by changing the temperature and concentration of acid used in the uronic determination from that generally used, additional distinguishing characteristics in the shape of the decarboxylation rate curve, useful for identifying uronic groups from different sources, might be brought out. This, however, was not the case. The employment of some reducing substance also failed to furnish any information as to the nature of uronic groups from different sources.

## SUMMARY

Some factors influencing the decarboxylation rate of apparent uronic groups of soil organic matter and uronic units of true pectin were investigated. The proportion of uronic carbon to organic carbon in the sample of Cheyenne fine sandy loam remained fairly constant although the organic carbon varied almost twofold. The presence of soil-absorbed $CO_2$, carbonates, and manganese oxides increased the yield of $CO_2$ during the first 15 minutes of boiling. Absorbed $CO_2$ may be removed by aerating for 4 hours in 12 per cent hydrochloric acid solution at room temperature with $CO_2$-free air. Three-tenths per cent or less of the total carbon of four pure hydroxy acids—$p$-hydroxy benzoic, salicylic, gallic, and ellagic acids—and of mixed phenolic acids isolated from redwood bark was evolved as $CO_2$ during the uronic determination. Lowering the temperature of the reaction from 135° to 110° during the uronic determination reduced the quantity of $CO_2$ evolved from soil organic matter and pectin and moderated the intensity of rate of evolution early in the determination. Lowering the concentration of hydrochloric acid from 12 per cent to 7.28 per cent had an even greater effect. Reducing substances decreased the yield of $CO_2$ from soil organic matter and pectin. This decrease was fairly uniform throughout the decarboxylation period. Soils added to pectin had no particular influence on the rate of decarboxylation of the uronic units from either source.

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# SOIL ORGANIC NITROGEN: I. NATURE OF THE ORGANIC NITROGEN IN A MUCK SOIL FROM GENEVA, NEW YORK

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It is generally assumed that most of the organic nitrogen in soil is protein in nature. There is at present, however, no clear-cut method of differentiating protein nitrogen from nonprotein nitrogen in soil. That some protein or protein-like materials exist in soil is certain. Suzuki (22) isolated alanine, leucine, aminovalerianic acid, proline, and aspartic acid from hydrolyzates of "humic acids" by Fischer's esterification method. Robinson (16) isolated leucine and isoleucine from Michigan peats after hydrolysis with strong mineral acid. Schreiner and Shorey (17) isolated arginine and histidine from alkali extracts of soil and also demonstrated the presence of lysine (20). The amino acid composition of the water-soluble fraction of soil was studied by Kivekäs (8). Approximately 10 per cent of the total water-soluble nitrogen was accounted for as individual amino acids or groups of amino acids after hydrolysis.

The protein nature of soil organic nitrogen has been studied in the past chiefly by the Hausmann method of protein analysis. In this method, the protein is hydrolyzed with strong mineral acid and the nitrogen of the hydrolyzate is distributed by appropriate means into the following groups: ammonia and amide, basic (diamino), nonbasic (monoamino), and humin. A large number and variety of soils have been subjected to the Hausmann analysis or related methods (2, 3, 4, 5, 6, 7, 9, 13, 15, 18, 20), and the results all show that some nitrogen occurs in each fraction. The nitrogen distributions in general show some similarity to those obtained from plant and animal proteins, the chief difference being in the higher humin and amide nitrogen values in the case of soil organic matter.

Shorey (21) has critically summarized the status of nitrogen in each of the fractions of the Hausmann analysis as follows:

*Ammonia and amide nitrogen.* There is little doubt that some ammonia is formed on hydrolysis, but it is still a question whether or not some of the ammonia may not be formed from some as yet unrecognized constituent of the acid solution by magensium or calcium oxide used to drive off ammonia.

*Dibasic nitrogen.* This fraction is determined by precipitation with phosphotungstic acid and in the case of protein the constituent diamines have been separated and identified. . . . Phosphotungstic acid, however, is a somewhat general precipitant for organic bases and in the case of soils the presence of nitrogen bases as yet unidentified is a possibility.

*Monoamino nitrogen.* In the method of Van Slyke which is now generally used in the study of hydrolysis products, the monoamino nitrogen is measured by the volume of nitrogen liberated with sodium nitrite under certain conditions. In the case of soils the only

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certainty is that there is, in this fraction, some amino compound or compounds that lose nitrogen on diazotization at room temperature.

*Humin nitrogen.* This is the nitrogen contained in the precipitate formed on making the acid solution alkaline with magnesium or calcium oxide. The nitrogen in this fractione of may be in part a secondary product formed by polymerization or condensation of som the primary splitting products. . . .

One may conclude from these remarks that until the chemical nature and protein derivation of the various nitrogen products of hydrolysis are known with more certainty, the results of Hausmann analyses of soil cannot be properly evaluated in terms of protein quality or quantity.

It has been routine practice to estimate the protein content of soils by multiplying the total organic nitrogen by the arbitrary factor 6.25, which assumes that all the organic nitrogen in soil is protein in nature. The problem of finding a method of determining the true protein content of soil organic matter can be approached in two ways: first, by direct extraction or separation of the protein materials from the rest of the organic matter; and second, by quantitative determination of the products of soil protein hydrolysis.

A quantitative separation of protein material from soil organic matter by the usual protein extraction procedures is not likely to prove very successful, as past work has shown (5, 13). The solubility behavior of complex compounds of high molecular weight, such as proteins in a mixture of other high polymers with which there may be various kinds and degrees of association, may be extremely difficult. A sharp separation of diverse kinds of materials of high molecular weight is not always easily accomplished, and resort must often be made to highly refined techniques such as selective adsorption or electrophoresis. The failure of soil protein material to show the usual protein reactions such as differential solubility (13) and rapid degradation by proteolytic enzymes (1, 6) has led to the idea that protein materials in soil may not exist free or in an easily dissociable form (5, 26). Whatever the actual state of protein combination in soil may be, it does not appear likely that a characteristic soil protein fraction can be quantitatively separated from soil organic matter by simple extraction methods.
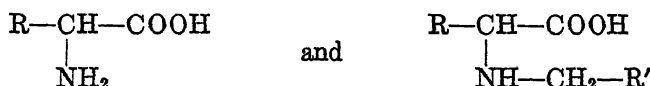
A quantitative determination of the products of soil protein hydrolysis as an approach to the problem requires a knowledge of the products formed and accurate methods for their estimation. The final end-products of protein hydrolysis are principally $\alpha$-amino acids, the fundamental units of protein structure. Some ammonia is liberated from amide linkages in the glutamic and aspartic acid units. Other nitrogen compounds may arise from the prosthetic groups of complex proteins, such as purines and pyrimidines from the nucleic acid of nucleoproteins. The humin nitrogen found after hydrolysis of "pure" proteins with strong mineral acid is regarded as an artifact, the result of condensation of amino acids (tryptophane and tyrosine) with aldehydes. Though it may be an insuperable task to identify and determine all the individual products of soil protein hydrolysis, this method of approach seemed to offer possibilities of obtaining a closer approximation to the true protein content of soils.

The purpose of the present investigation was to study the chemical nature and

protein derivation of the nitrogen compounds appearing in the various fractions of the Hausmann analysis. This paper is concerned with the amino nitrogen and humin nitrogen fractions, which together constitute a large part of the organic nitrogen in many soils.

The so-called diamino and monoamino fractions of the Hausmann analysis yield nitrogen in the usual Van Slyke manometric nitrous acid method. This reaction is characteristic of free amino groups and the rate of reaction is dependent on the structure of the amino compound. With amino acids the rate is very rapid and in the usual 3- or 4-minute runs the amount of nitrogen evolved from other amino compounds may be slight if these are present in only small amounts. The nonspecificity of the reaction leaves much to be desired, however, in determining amino nitrogen in soil products.

In the present study of the amino fractions of the Hausmann analysis, Van Slyke's decarboxylation method with ninhydrin was employed (24). According to Van Slyke (25), molecular structures which provide carboxyl groups yielding carbon dioxide quantitatively by reaction with ninhydrin under the conditions of the analysis are:

$$R\text{---}\underset{\underset{NH_2}{|}}{CH}\text{---}COOH \quad \text{and} \quad R\text{---}\underset{\underset{NH\text{---}CH_2\text{---}R'}{|}}{CH}\text{---}COOH$$

Ammonia, amides, and glucosamine do not react. Aspartic acid, however, yields two moles of carbon dioxide.

The humin nitrogen in a Hausmann analysis of soil is generally high. In some cases (20) more than 50 per cent of the total soil nitrogen may be found in this fraction. Humin nitrogen seldom exceeds a few per cent when "pure" proteins are hydrolyzed with acid. The unusually large amounts of humin nitrogen determined in soil may be due to the presence of nitrogenous nonprotein materials in the soil, formation of humin by secondary reactions during acid hydrolysis, and protein materials in soil which resist strong acid hydrolysis and which in the scheme of analysis would appear in the humin nitrogen fraction (12).

In an attempt to distinguish nitrogenous nonprotein material from humin formed by secondary reactions, some studies on alkaline hydrolysis were carried out. Lugg (11) has shown that in the absence of air and other oxidizing agents, proteins can be hydrolyzed in an alkaline medium with little or no humin formation.

<div align="center">EXPERIMENTAL</div>

A muck soil from Geneva, New York, containing 2.31 (oven-dry basis) per cent total nitrogen was used in these studies. The soil was air-dried and ground to pass through an 80-mesh screen.

### Methods of nitrogen analysis

*Total nitrogen*—determined by the micro Kjeldahl method with $CuSO_4$ as catalyst.

*Ammonia and amide nitrogen*—determined by distillation with freshly ignited MgO at

45 to 50° under reduced pressure. In certain cases the determination was carried out at 100°.

*Amino nitrogen*—determined by Van Slyke's decarboxylation method with ninhydrin using the titration method (24). A 7-minute heating period at pH 2.5 was used. Amino nitrogen was also determined by the usual Van Slyke micromanometric nitrous acid method (23). The time allowed for deamination was 4 minutes at room temperatures ranging from 25 to 30°.

## Hausmann analysis of muck soil

Ten grams of finely ground, air-dry soil was refluxed with 200 cc. of 20 per cent HCl for 20 hours. The hydrolysis mixture was filtered and the residue containing the acid-insoluble humin nitrogen washed with small portions of hot $N$ HCl. The combined filtrate was concentrated to a sirup under reduced pressure at 50 to 60°. Water was added and the mixture concentrated again. This operation was repeated three times in order to remove free HCl as completely as possible.

A slight excess of freshly ignited MgO was added to the aqueous hydrolyzate and the ammonia removed and determined. The mixture in the distillation flask was filtered and the precipitate thoroughly washed with hot water. The precipitate contains the acid-soluble humin nitrogen.

The filtrate from the MgO precipitate was slightly acidified with HCl, concentrated under reduced pressure to 25 cc., and transferred to a 125-cc. Erlenmeyer flask. Then 4.5 cc. of concentrated HCl and 3.75 gm. of phosphotungstic acid dissolved in 12.5 cc. of water were added and the mixture was diluted to 50 cc. The clear supernatant liquid was tested for complete precipitation of bases by addition of a few drops of phosphotungstic acid solution (2.5 per cent phosphotungstic acid in 3.5 per cent HCl). The flask was heated on a steam bath for 1 hour and allowed to stand in the refrigerator for 3 days. The phosphotungstic acid precipitate was filteredon a chilled Büchner funnel and the precipitate was washed with small portions of ice-cold phosphotungstic acid solution.

The phosphotungstic acid precipitate was dissolved in the smallest possible quantity of dilute NaOH, and the phosphotungstate was precipitated with BaCl₂ solution. Barium phosphotungstate was filtered off and washed with hot water. The combined filtrate is the basic nitrogen fraction.

The filtrate from the phosphotungstic acid precipitation is the nonbasic nitrogen fraction.

Table 1 gives the results of the Hausman analysis.

The nitrogen distribution in the Hausmann analysis of the muck soil is not unlike others reported in the literature. The total humin nitrogen, 33 per cent of the total nitrogen, is considerably higher than is usually found by acid hydrolysis for animal and plant proteins. The total amino nitrogen determined by the decarboxylation method accounts for 37 per cent of the total soil nitrogen. The basic amino nitrogen is very low amounting to only 3.78 per cent of the total nitrogen and 10 per cent of the total amino nitrogen. Low values for basic nitrogen are characteristic of soil organic matter and are consistent with observations that basic amino acids are rapidly destroyed when added to soil in the form of protein (9, 10). The nonamino nitrogen of the basic fraction, on the other hand, is relatively high, and a large part of this nitrogen is liberated at 100° as volatile base. Ammonia may be evolved at this temperature from decomposition of arginine. A systematic study of the ammonia and amide fraction has not yet been undertaken to determine the sources from which ammonia and other volatile bases may arise under different conditions.

The nonbasic amino nitrogen accounts for approximately one third of the total nitrogen of the soil and indicates that the soil proteins are made up largely of monoamino acids. Of the total amino nitrogen, 90 per cent is in the nonbasic amino nitrogen (monoamino) fraction.

TABLE 1

*Hausmann analysis of a muck soil from Geneva, New York.*

| FRACTION | QUANTITY PER 10 GM. MUCK | PERCENTAGE OF | | |
|---|---|---|---|---|
| | | Total N | Acid-soluble N | Total amino N |
| | *mgm.* | | | |
| Total soil N | 203.5 | 100.0 | ..... | ..... |
| Total acid-soluble N | 148.1 | 72.8 | 100.0 | ..... |
| Total amino N | 74.8 | 36.8 | 50.5 | 100.0 |
| Ammonia and amide N* | 20.8 | 10.2 | 14.0 | ..... |
| Total humin N | 67.7 | 33.2 | ..... | ..... |
| Acid-insoluble humin N | 55.4 | 27.2 | ..... | ..... |
| Acid-soluble humin N | 12.3 | 6.0 | 8.3 | ..... |
| Basic nitrogen | 42.3 | 20.8 | 28.5 | ..... |
| Amino N (by decarboxylation) | 7.7 | 3.8 | 5.2 | 10.3 |
| Nonamino N† | 34.6 | 17.0 | 23.3 | ..... |
| Nonbasic nitrogen | 75.8 | 37.2 | 51.2 | ..... |
| Amino N (by decarboxylation) | 67.1 | 33.0 | 45.3 | 89.7 |
| Nonamino N | 8.6 | 4.3 | 5.8 | ..... |

* Ammonia and amide nitrogen includes 1 mgm. $NH_3$-nitrogen in the soil before hydrolysis.

† 18.7 mgm. of the nonamino basic nitrogen was evolved as volatile bases when distilled with MgO at 100°. Nonamino nitrogen was calculated as the difference between total and amino nitrogen.

### Amino nitrogen determinations by decarboxylation and nitrous acid methods

Amino nitrogen determinations by the nitrous acid method were carried out on aliquots of the basic and nonbasic fractions of the Hausmann analysis. Results of amino nitrogen determinations by the nitrous acid method and the decarboxylation method are compared in table 2.

The amino nitrogen in the basic fraction as determined by the nitrous acid method is two and a half times as great as by the decarboxylation method. The basic fraction apparently contains a large amount of amino compounds which are not α-amino acids but which react with nitrous acid to yield nitrogen.

In the nonbasic fraction, the amino nitrogen by decarboxylation is slightly higher than by the nitrous acid method. This discrepancy may be due to aspartic acid, which gives two moles of carbon dioxide by decarboxylation with ninhydrin.

On the assumption that the difference in amino nitrogen by the two methods is due to aspartic acid, aspartic acid accounts for 6.98 per cent of the total amino nitrogen of the soil hydrolyzate.

*Nitrogen distributions obtained by alkaline and acid hydrolysis*

*Alkaline hydrolysis under reflux open to air*—10 gm. of muck soil was hydrolyzed with 100 cc. of 5 N NaOH under reflux open to air for 24 hours. The mixture was cooled, acidified with HCl, and filtered. The acid filtrate was analyzed for ammonia and amide nitrogen, acid-soluble humin nitrogen, total amino nitrogen by decarboxylation, and total nonamino nitrogen. Total nitrogen was determined on the acid-insoluble residue (insoluble humin nitrogen). The results are shown in table 3.

*Alkaline hydrolysis in sealed tubes*—5 gm. of muck soil was hydrolyzed with 25 cc. of 5 N NaOH in sealed tubes with a 2 cc. air space, in a boiling water bath for 24 and 48 hours. The hydrolyzates were treated and analyzed as described above. The results are shown in table 3.

The nitrogen distributions of casein and a casein-soil mixture were also determined. One gram of high-purity casein was hydrolyzed with 25 cc. of 5 N NaOH for 24 hours in a sealed tube. In another tube, a mixture of 1 gm. of casein and 5 gm. of muck soil was similarly hydrolyzed. The nitrogen distributions and recoveries of nitrogen are shown in table 4.

TABLE 2

*Comparison of amino nitrogen determinations by decarboxylation method and nitrous acid method in amino fractions of the muck hydrolyzate*

| METHOD | BASIC N FRACTION | NONBASIC N FRACTION |
|---|---|---|
| | *mgm.** | *mgm.** |
| Decarboxylation method..................... | 7.69 | 67.14 |
| Nitrous acid method........................ | 20.41 | 62.26 |

* NH₂-N per 100 gm. muck.

3. *Acid hydrolysis*—In order that results of alkaline and acid hydrolysis be comparable, a nitrogen distribution of an acid hydrolyzate was determined in the same manner as for the alkaline hydrolyzates. Five grams of muck soil was hydrolyzed with 100 cc. of 20 per cent HCl under reflux for 24 hours. The HCl was removed by distillation under reduced pressure and the fractionations and analyses were carried out in the usual manner. The results of acid hydrolysis are shown in table 3.

Tests for tryptophane and tyrosine were made on the various hydrolyzates. The p-dimethyl-aminobenzaldehyde color reaction was used as a test for tryptophane and the α-nitroso-β-naphthol color reaction for tyrosine (14).

No tryptophan was detected in either acid or alkaline hydrolyzates of soil. Traces of tyrosine, however, were present in both acid and alkaline hydrolyzates. Both amino acids were readily detected in the alkaline hydrolyzates of the casein-soil mixture.

The data in table 3, taken as a whole, show that the nitrogen distributions of alkaline and acid hydrolyzates of soil are not greatly different. The most significant feature of alkaline hydrolysis is the large amount of humin nitrogen still present after 48 hours. The amount of unhydrolyzed protein in the humin fraction is probably small, since heating 24 to 48 hours did not reduce humin nitrogen significantly. It is also unlikely that any large part of the humin nitrogen

was formed during hydrolysis by secondary reactions between protein decomposition products and carbohydrates. The results in table 4 indicate that no appreciable amount of humin nitrogen, over and above that found for casein and soil hydrolyzed alone, was formed when a mixture of soil and casein was hydrolyzed under the same conditions.

TABLE 3

*Nitrogen distributions in alkaline and acid hydrolyzates of muck soil*

(Percentages of total soil nitrogen)

| FRACTION | 5 N NaOH HYDROLYSIS | | | 20 PER CENT HCl HYDROLYSIS |
|---|---|---|---|---|
| | Under reflux 24 hours | In sealed tube 24 hours | In sealed tube 48 hours | Under reflux 24 hours |
| | *per cent* | *per cent* | *per cent* | *per cent* |
| Total humin N | 33.60 | 40.56 | 38.84 | 34.62 |
| Acid-insoluble N | 23.90 | 26.53 | 24.90 | 28.95 |
| Acid-soluble N | 9.70 | 14.03 | 13.94 | 5.67 |
| NH$_3$ and amide N* | 8.98† | 22.30 | 22.85 | 21.09 |
| Total amino N (by decarboxylation) | 34.00 | 29.50 | 33.81 | 32.11 |
| Total nonamino N | 1.22 | 6.72 | 6.44 | 7.72 |

* NH$_3$ and amide N was determined at 100°.
† This value does not include ammonia lost during hydrolysis.

TABLE 4

*Recoveries of casein nitrogen from a casein-soil mixture**

| FRACTION | CASEIN | SOIL | CASEIN-SOIL MIXTURE | RECOVERY |
|---|---|---|---|---|
| | *mgm.†* | *mgm.‡* | *mgm.* | *per cent* |
| Acid-soluble humin N................ | 7.18§ | 14.28 | 22.14 | 109.47 |
| NH$_3$ and amide N.................... | 25.85 | 22.69 | 47.35 | 95.40 |
| Total amino N....................... | 75.74 | 30.02 | 105.83 | 100.10 |

* Hydrolyzed with 5 N NaOH for 24 hours.
† Per gram.
‡ Per 5 gm.
§ The alkaline hydrolyzate of casein was clear. Acidification produced turbidity which was probably due to protein not completely hydrolyzed (casein is one of the most difficult proteins to hydrolyze completely). The humin nitrogen of casein comes from this material, which was carried down by MgO.

The close agreement of humin nitrogen values obtained by alkaline and acid hydrolysis indicates that acid hydrolysis does not lead to appreciable humin nitrogen formation by secondary reactions. This is in accord with the observation that tryptophan was absent from alkaline hydrolyzates of muck. It is doubtful that tyrosine contributed significantly to humin formation during hydrolysis, inasmuch as only traces were detected in both acid and alkaline hydrolyzates of muck.

The results of acid and alkaline hydrolysis of the muck from Geneva indicate

that the large amounts of humin nitrogen found after strong acid hydrolysis are probably not due, to any large degree, to secondary reactions involving amino acids or to unhydrolyzed soil protein.    Most of the humin nitrogen probably exists in the soil in the form of nonprotein materials, perhaps as complex, heterocyclic nitrogen compounds.    On this basis, not more than 66 to 75 per cent of the total organic nitrogen of the muck soil can be regarded as protein in nature.

## SUMMARY

The α-amino acid character of a large part of the hydrolyzed organic nitrogen of a muck soil from Geneva, New York, was confirmed by decarboxylation with ninhydrin.    About 37 per cent of the total nitrogen of the soil was accounted for as α-amino nitrogen by the decarboxylation method.

Some studies on alkaline hydrolysis of the muck soil were carried out in order to determine whether the large amounts of humin nitrogen found after acid hydrolysis are derived from protein.    Alkaline hydrolysis yielded as much humin nitrogen as did acid hydrolysis.    It was concluded that most of the so-called humin nitrogen is already present in soil as nonprotein material, perhaps as complex, heterocyclic nitrogen compounds.

On the basis of the amino and amide nitrogen determinations on the products of hydrolysis, at least 50 per cent of the total organic nitrogen in the muck soil may be protein in nature.    Since alkaline hydrolysis has shown that the humin nitrogen is probably not derived from protein, not more than 66 to 75 per cent of the total organic nitrogen in the muck soil can be considered protein nitrogen.

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# William Horace Ross

## 1876–1947

William Horace Ross, principal chemist in the Division of Soils, Fertilizers, and Irrigation, U. S. Department of Agriculture, authority on fertilizer materials and mixed fertilizers, died at the age of 71 in Washington, D. C., May 16, 1947, after a brief illness.   He was born of Scotch parents at River John, Nova Scotia.

He received his bachelor of science and master of science degrees from Dalhousie University, Canada, in 1903 and 1904, respectively.   After one year at Johns Hopkins on a fellowship, he transferred to the University of Chicago as special assistant working with Herbert N. McCoy on uranium and thorium. His doctoral thesis at Chicago in 1907 was on the radioactivity of thorium and uranium.

While at Chicago, Dr. Ross was impressed with soil problems by the early work of Milton Whiteny, Frank K. Cameron, Oswald Schreiner, and others in the Bureau of Soils, and forthwith decided that he would endeavor to become associated with that Bureau.

His first work in agriculture, however, was as assistant chemist at the Arizona Agricultural Experiment Station from 1907 to 1912.   There he was engaged in determining the composition of irrigation water.   Material gathered then was later used in a publication issued through the Carnegie Institution of Washington on "The annual variation of concentration of saline components in water of the Salton Sea."

Dr. Ross' service in the U. S. Department of Agriculture began January 31, 1912, and for the next 34 years, to his retirement December 1, 1945, he was engaged on virtually every phase of fertilizer work, except for part of a year during World War I, when he was a captain in the Chemical Warfare Service.   During his employment in the Department of Agriculture he was author or co-author of 135 publications devoted to some phase of fertilizers.   Previously he had issued 16 publications, including his doctoral dissertation.   Six of this group, published from 1906 to 1911, concerned radioactivity of elements; one was on the chemical action of ultraviolet light.   His first agricultural paper, "The Nutritive Value of Cholla Fruit," was published while at the Arizona Experiment Station.   Dr. Ross was one of the few persons employed to work on fertilizer problems under the first appropriation granted the Department of Agriculture for that purpose and the only one of the group who was still employed on these investigations at the time of his death.   Over this entire period he was devoted wholeheartedly to one end—the production of more efficient fertilizers at lower cost to the farmer.

Among the notable contributions of Dr. Ross were the first production of phosphoric acid by the electric furnace method; the detection of boron toxicity in an American potash material and an indication of permissible quantity in fertilizer; the preparation of high-analysis fertilizers; economies in the use of these and double-strength fertilizer mixtures; reactions due to the ammoniation of

superphosphates and the control of reactions in mixed fertilizers; granulation of fertilizers; improvements in mixed fertilizers; and most recently, 1943–1945, leadership in the conditioning of ammonium nitrate to make it acceptable in commerce and for use by farmers. His accomplishments, particularly in the



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formulation and technology of mixed fertilizers and in methods for evaluating the availability of plant foods, won for him recognition as a leading authority on these subjects. He lived to know the esteem with which industry regarded his work and the benefits accruing to the consumer from his efforts.

After his retirement, Dr. Ross was collaborator in the Division of Soils,

Fertilizers, and Irrigation of the Department of Agriculture and was also consultant to the National Fertilizer Association.

From the beginning of *Chemical Abstracts* he was an abstractor, and part of the time was associate editor on radioactivity. He was a member of the American Association for the Advancement of Science; the American Chemical Society; the American Society of Agronomy; the American Institute of Chemists; the Association of Official Agricultural Chemists; and Sigma Xi. He was past president of the Association of Official Agricultural Chemists.

Clinging to his Scotch presbyterianism, he had been an officer in his church for many years. His life was centered about his home, his wife Catherine Allen, and his two sons Allen Murray and William Horace, Jr.

On the personal side, Dr. Ross always took a deep interest in those working under his direction. Frequent talks, discussions, and conferences kept him well informed on the progress of their work and gave him the opportunity to offer suggestions. His gentle manner and kindly disposition endeared him to his associates. While accomplishing much, he was never too busy to discuss the problems of others.

His Scotch presbyterianism was accompanied by the traditional steadiness of purpose and firmness in opinions. But once converted to another viewpoint, he espoused the new position as firmly as the first. The intensity of his concentration often resulted in the scientists' proverbial absent-mindedness or a disdain for commonplace or inconsequential things. These personal characteristics only endeared him the more to his associates.

R. O. E. DAVIS

# FACTORS INFLUENCING INFILTRATION RATES INTO YOLO LOAM

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Information is here reported on changes in infiltration rates into Yolo loam with differential treatments involving cropping practices, application of organic matter, disposal of crop re`idue, shading the surface, cultivation, and type fertilizer used. The experiments were conducted in 3-foot by 3-foot vertical side plots, pictured in figure 1. Originally, in 1940 and 1941, there were 32 such plots
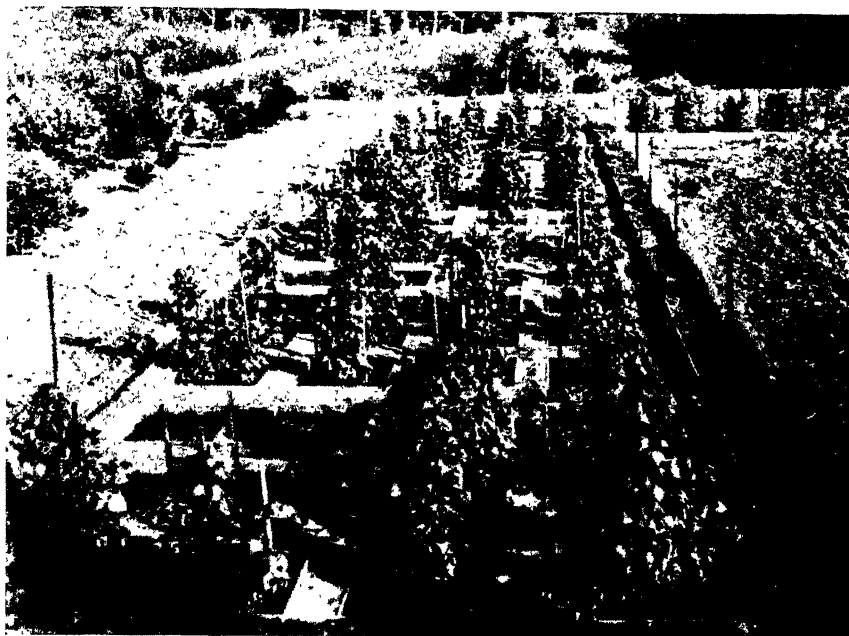


FIG. 1. VIEW OF THE INFILTRATION BASINS SHOWING A BEAN PLANTING IN THE PERIODICALLY CROPPED PLOTS, NOVEMBER 18, 1942

with eight treatments. Preliminary data from these original plots have been published (5), but are briefly repeated here because of additional data. A more comprehensive program was instituted in 1941 on 96 plots with 24 treatments. This comprehensive program had to undergo rather continuous modification. The data, therefore, are, in some respects, not so complete as originally planned.

With irrigated agriculture, information on infiltration rates is of utmost importance in planning layouts and irrigation practices. With a given soil such rates are known to vary widely, and the objective of the experiment was to deter-

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mine to what degree several factors affected those rates. Yolo loam, on which the experiments were conducted, is one of the better California soils. It is a recent alluvium derived from sedimentary parent material. The chemical nature of the water used in irrigation may affect infiltration, but that was not herein a variable. Los Angeles City water was used throughout. A typical analysis of this water, in equivalents per million, follows: Ca 1.6, Mg 0.8, Na 1.7, K 0.1, $CO_3$ + $HCO_3$ 2.5, $SO_4$ 1.2, Cl 0.6.

## METHOD OF STUDY

Water was admitted to the basins through a hose into which was connected a water meter. A measured amount, to provide an irrigation 4 or 2 inches deep, was applied in a period of less than 1 minute. An effort was made to devise a method of application to minimize surface turbulence. Most consistent results were obtained simply by placing a canvas sack over the end of the hose so that the water was applied over a large area at low velocity, and that method was used throughout. There was still, however, considerable surface turbulence, and where any appreciable amount of litter covered the surface it was lifted off while the water was being applied, to help equalize the effect. At first, average infiltration rates were computed from the time required for the water to enter the soil. This procedure was later somewhat modified.[2]

There were four basins for each treatment. The plots were arranged in four rows, with one plot of each treatment in each row, as shown in figure 1. Comparison of all outside plots with all inside plots for the first 10 irrigations showed an average rate relationship of 5.6 to 5.4, indicating that there was no appreciable border effect on the rates.

With the original 32 plots, infiltration rates for bare basins were compared with those for cover-cropped basins, those for shaded basins, those for cultivated basins, and those for basins with an organic mulch. With the cover-cropped basins, the clipped tops were in some instances left on the soil surface to decay, and in some instances were removed.

With the 96 basins the work was expanded to include the effect of moderate applications of several commercial fertilizers, and to include a contrasting range of types of crop. The fertilizers used were Uramon, ammomium sulfate, and sodium nitrate. They were applied once a year at the rate of 100 pounds of nitrogen per application. The method of application varied somewhat, as described in the results. As to cropping, it was decided to maintain a permanent sod in some basins, and in other basins to plant crops that would have no appreciable effect in decreasing surface turbulence during irrigation. Crops used were corn, pole beans, and peas. As it was necessary to cultivate the basins where sod was to be planted, at that time all basins were cultivated to a depth of 1 inch. At the same time, basins where tillage was a regular operation were cultivated to a depth of 4 inches. To eliminate cultivation effects with periodically cropped

[2] Modifications in the procedure are shown in table 3. It should be noted that the pre-irrigations applied for a period naturally depressed the rates found for the measured irrigations of that period.

basins thereafter, seeds were planted merely by poking a small hole in the ground, placing the seeds, and covering. There were four such planting spots per basin. Old crops were removed by cutting them off at the surface. Table 1 lists the various treatments used.

TABLE 1

*List of treatments and variables involved*

| TREAT-MENT NUMBER | EXPOSURE OF SURFACE SOIL | DISPOSAL OF CROP RESIDUE | CULTIVATION | FERTILIZATION* |
|---|---|---|---|---|
| | | | | |
| *A. Bare of vegetation (no crops, periodically hand-weeded)* | | | | |
| 1† | Ventilated shade‡ | None | None | Uramon |
| 2† | Bare | None | None | Uramon |
| 3† | Bare | None | Hand-cultivated | Uramon |
| 4† | 4 inches Organic mulch | None | None | Uramon |
| *B. Periodically cropped (barley for original treatments, thereafter corn, beans, and peas)* | | | | |
| 5† | Crop residue | Left on surface | None | Uramon |
| 6† | Bare | Removed | None | Uramon |
| 7† | Crop residue | Worked into soil‖ | Hand-cultivated | Uramon |
| 8† | Bare | Removed | Hand-cultivated | Uramon |
| 9 | Crop residue | Left on surface | None | Uramon |
| 10 | Bare | Burned** | None | Uramon |
| 11 | Bare | Burned** | Hand-cultivated | Uramon |
| 12 | Crop residue | Left on surface | None | Ammonium sulfate |
| 13 | Crop residue | Left on surface | None | Sodium nitrate |
| 14 | Crop residue | Worked into soil‖ | Hand-cultivated | Ammonium sulfate |
| 15 | Crop residue | Worked into soil‖ | Hand-cultivated | Sodium nitrate |
| 23 | Bare | Removed | None | Ammonium sulfate |
| 24 | Bare | Removed | None | Sodium nitrate |
| *C. Permanent sod maintained; tops (crop residue) periodically clipped* | | | | |
| 16 | Sod | Left on surface | None | Uramon |
| 18 | Sod | Left on surface | None | Ammonium sulfate |
| 19 | Sod | Left on surface | None | Sodium nitrate |
| 20 | Sod | Removed | None | Uramon |
| 21 | Sod | Removed | None | Ammonium sulfate |
| 22 | Sod | Removed | None | Sodium nitrate |

\* All fertilization at rate of 100 pounds nitrogen per acre per application.

† The eight original treatments.

‡ Ventilated shades in place only a few days up to April 1941, then off for winter of 1941–42. On April 18, 1942 new louvre type covers installed which were left on continuously. These admitted rain, but provided full shade.

§ Diatomaceous earth at rate of 4 tons per acre applied February 14, 1942. Plots were not cultivated from February 14, 1942 until January 14, 1943.

‖ Left on surface until next cultivation.

\*\* Crop residue burned with aid of a weed burner.

Cultivation was done with shovel, hoe, and rake. Such hand-cultivation could not produce compaction or "plow sole" which, on this soil, could have a drastic effect upon infiltration (2, 3). Weeds were pulled by hand in all plots at frequent intervals,[3] and no cultivation was practiced except as specifically provided in treatments.

In October 1941 a $\frac{1}{8}$-inch surface crust of soil was skimmed from all plots, and soil tube samples to a depth of 2 feet were obtained from all plots. This operation modified somewhat the original eight treatments.

When soil is cultivated, it is bulked and dries out significantly more than uncultivated soil. This results in an appreciable increase in the initial infiltration rates. To overcome this effect, from May 1942 through 1943 the basins were irrigated with a 2-inch application several hours before the application used to determine infiltration rates was made.
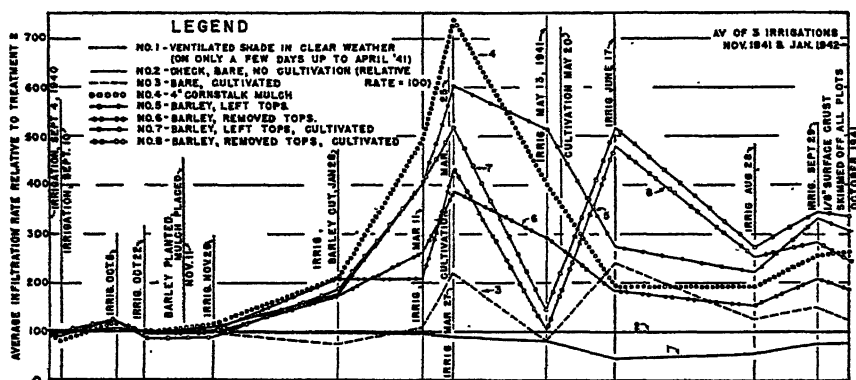


FIG. 2. RELATIVE INFILTRATION RATES FOR EACH TREATMENT (FOUR BASINS) AT EACH IRRIGATION, ORIGINAL TREATMENTS

RESULTS FOR ORIGINAL PROGRAM

Results of the original program, as well as dates when the various operations were performed, are shown in figure 2. Here "relative rates" are used for infiltration because of variation of actual rates with the preirrigation moisture content of the soil. All rates are related to treatment 2 (assigned a value of 100 for each irrigation) with adjustments for pretreatment relationships.

These data show:

1. Where a mulch of organic matter or a crop residue was placed on the soil surface, infiltration rates increased up to sevenfold over bare nontilled treatments. These effects became most prominent after decomposition of the mulches was well advanced. Organic matter left on the surface seems to give a more rapid infiltration response than material cultivated into the soil.

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[3] By 1944 it had become impossible to weed at frequent enough intervals. This was particularly true from February to April 1944, and from August 1944 to August 1945. During this last period weed growth became exceedingly rank, and, although all weeds, when pulled, were removed from the basins, there was undoubtedly an appreciable effect in drying out the soil and in supplying a source of organic matter.

2. The principal effect of hand cultivation on infiltration was in the first irrigation following cultuvation.

3. Shade decreased infiltration rates, as will be discussed later.

4. The skimming of a ½-inch crust from the surface of the basins did not materially affect the infiltration characteristics of the plots.

On the surface crust and 0- to 1-foot soil samples collected in October 1941, certain laboratory analyses were made which, it was thought, might indicate the condition of the soil. A summary of these is shown in table 2. They demonstrated a tendency for salines to concentrate in the top crust when there is no cultivation, and for organic matter and cultivation to cause some improvement in the physical condition of that crust. Some rough base-exchange determinations

TABLE 2

*Laboratory analyses of soils from infiltration plots, collected October 1941*

| TREATMENT | SURFACE CRUST SAMPLES | | | | | SAMPLES FROM 0- TO 12-INCH DEPTH | | | |
|---|---|---|---|---|---|---|---|---|---|
| | pH* | Specific electric conductance† | Macro-porosity‡ | Infiltration Rate§ | Moisture equivalent | pH* | Specific Electric Conductance† | Air-dry Moisture | Moisture Equivalent |
| | | $K \times 10^5$ at 25°C. | per cent | Inches per hr. | per cent | | $K \times 10^5$ at 25°C. | per cent | per cent |
| Original plots | | | | | | | | | |
| 1 | 7.6 | 51.6 | 15.4 | 1.7 | 19.0 | 7.2 | 14.3 | 3.8 | 21.6 |
| 2 | 7.6 | 54.2 | 15.9 | 1.2 | 20.8 | 7.3 | 15.5 | 3.7 | 21.6 |
| 3 | 7.7 | 28.2 | 14.9 | 2.3 | 22.8 | 7.3 | 14.4 | 3.4 | 21.3 |
| 4 | 7.0 | 80.3 | 17.3 | 2.3 | 22.7 | 7.2 | 16.6 | 3.6 | 21.1 |
| 5 | 7.1 | 109.4 | 16.9 | 1.7 | 23.1 | 7.3 | 16.7 | 3.4 | 21.1 |
| 6 | 7.4 | 95.4 | 15.7 | 1.1 | 21.4 | 7.3 | 16.0 | 3.7 | 21.3 |
| 7 | 7.4 | 32.0 | 13.8 | 2.3 | 19.4 | 7.1 | 14.7 | 3.5 | 21.3 |
| 8 | 7.6 | 29.8 | 15.0 | 2.3 | 19.3 | 7.2 | 14.6 | 3.8 | 21.2 |
| Range for all other plots | | | | | | | | | |
| | 6.7–7.2 | 52–89 | 14–16 | 1.8–2.9 | 20–22 | 6.6–7.0 | 13–21 | 3.9–4.5 | 21.8–22.4 |

* Of a 2:1 suspension.

† Of a 2:1 extract.

‡ Per cent by volume of moisture lost between tensions of 0 to 40 cm. water.

§ Average rate for first hour of laboratory packed samples ¾ inch deep, under 1-foot head.

were also made of the top crust of a few plots, but did not conclusively demonstrate significant differences.

### RESULTS OF COMPREHENSIVE PROGRAM

Average infiltration rates for each treatment for each irrigation under the comprehensive program are shown in table 3.[4] Likewise, that table shows variations in the depth of irrigation and method of measurement used.

[4] For the irrigations of June 28, 1943 and July 30, 1943 frequent readings were made of water levels in each basin for the purpose of obtaining curves of rate plotted against time. Logarithms of the data were plotted with time in minutes as abscissa and rate in inches per hour as ordinate. These showed considerable variation, although tending toward straight lines. Average slopes of these curves for each treatment ranged from −1.3 to −1.9 and showed no correlation with the operations.

## TABLE 8

Average infiltration rates,* in inches per hour, for treatments at each irrigation

| IRRIGATION | | TREATMENT NUMBER | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Depth | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17† | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | inches | | | | | | | | | | | | | | | | | | | | | | | | |
| Aug. 28, '41 | 4 | 2.06 | 4.04 | 4.90 | 7.06 | 8.31 | 6.56 | 10.56 | 9.37 | 12.06 | 12.40 | 12.19 | 11.92 | 13.58 | 12.53 | 7.30 | 8.79 | 9.93 | 12.16 | 10.68 | 9.46 | 6.61 | 11.34 | 10.11 | 9.05 |
| Sept. 29, '41 | 4 | 1.18 | 1.71 | 2.46 | 4.05 | 5.26 | 3.70 | 5.60 | 4.43 | 7.32 | 6.85 | 7.23 | 8.35 | 8.93 | 9.25 | 5.87 | 7.35 | 5.82 | 0.26 | 6.16 | 4.89 | 6.36 | 4.78 | 7.48 | 7.41 |
| Nov. 27, '41 | 4 | 1.01 | 1.36 | 2.24 | 2.94 | 3.18 | 2.72 | 4.15 | 3.54 | 5.33 | 5.48 | 6.24 | 7.46 | 6.76 | 6.87 | 5.36 | 5.76 | 6.50 | 5.38 | 4.80 | 3.46 | 4.04 | 4.20 | 6.88 | 5.76 |
| Jan. 8, '42 | 2 | 0.18 | 0.27 | 0.18 | 0.70 | 0.93 | 0.48 | 0.87 | 0.68 | 2.04 | 1.66 | 1.73 | 2.12 | 2.08 | 2.58 | 1.58 | 1.75 | 2.09 | 1.08 | 1.44 | 1.11 | 1.19 | 1.15 | 2.27 | 1.69 |
| Jan. 22, '42 | 2 | 0.36 | 0.50 | 0.62 | 1.17 | 1.38 | 1.10 | 1.66 | 1.47 | 2.34 | 1.63 | 1.70 | 2.22 | 3.00 | 3.07 | 1.93 | 1.95 | 2.82 | 2.22 | 1.99 | 1.27 | 1.48 | 1.51 | 3.90 | 2.65 |
| Apr. 3, '42 | 2 | 0.95 | 1.21 | 1.52 | 2.00 | 2.00 | 2.84 | 3.63 | 3.70 | 2.97 | 2.55 | 3.60 | 2.64 | 3.14 | 7.81 | 3.31 | 2.46 | 3.06 | 2.03 | 2.18 | 1.67 | 1.96 | 1.44 | 3.85 | 2.55 |
| May 7, '42 | 2–4 | 0.34 | 0.38 | 0.46 | 0.58 | 0.50 | 0.57 | 0.51 | 0.55 | 0.83 | 0.81 | 0.77 | 0.55 | 0.99 | 1.61 | 0.47 | 0.91 | 1.44 | 1.14 | 1.03 | 0.79 | 1.00 | 0.79 | 1.14 | 0.83 |
| June 4, '42 | 2–4 | 0.42 | 0.55 | 0.65 | 0.78 | 0.64 | 0.67 | 0.64 | 0.60 | 0.89 | 0.64 | 0.74 | 0.56 | 0.87 | 1.16 | 0.70 | 1.03 | 1.49 | 1.28 | 1.03 | 0.72 | 0.94 | 0.91 | 1.00 | 0.86 |
| July 1, '42 | 2–4 | 0.66 | 0.71 | 0.94 | 0.75 | 0.78 | 0.84 | 0.71 | 0.68 | 0.87 | 0.78 | 0.81 | 0.92 | 0.90 | 1.14 | 0.57 | 0.92 | 1.36 | 1.13 | 1.04 | 0.76 | 1.10 | 0.89 | 0.92 | 0.70 |
| Aug. 20, '42 | 2–4 | 0.84 | 1.02 | 1.21 | 3.88 | 1.67 | 1.61 | 1.70 | 1.42 | 1.62 | 1.35 | 1.55 | 1.58 | 1.73 | 2.32 | 1.08 | 1.25 | 1.63 | 1.38 | 1.93 | 1.14 | 1.30 | 1.12 | 1.67 | 1.33 |
| Oct. 27, '42 | 2–4 | 0.76 | 0.84 | 1.14 | 1.43 | 1.47 | 1.40 | 1.62 | 1.20 | 1.30 | 1.26 | 1.40 | 1.37 | 1.47 | 1.86 | 1.12 | 1.36 | 1.57 | 1.29 | 1.55 | 1.25 | 1.55 | 1.30 | 1.38 | 1.32 |
| May 27, '43 | 2–4 | 0.07 | 1.16 | 1.00 | 2.81 | 2.96 | 2.32 | 2.59 | 1.47 | 2.74 | 2.15 | 2.19 | 3.32 | 2.85 | 3.58 | 2.27 | 3.04 | 2.99 | 2.47 | 3.14 | 2.77 | 2.06 | 2.69 | 2.26 | 2.06 |
| June 28, '43 | 2–4 | 0.81 | 1.06 | 1.57 | 1.70 | 1.84 | 1.60 | 1.50 | 1.03 | 1.53 | 1.47 | 1.37 | 1.60 | 1.94 | 1.95 | 0.98 | 1.00 | 1.14 | 1.04 | 1.17 | 0.87 | 0.95 | 0.78 | 1.61 | 1.08 |
| July 30, '43 | 2–4 | 0.85 | 1.01 | 1.37 | 1.44 | 1.32 | 1.30 | 1.09 | 0.91 | 1.31 | 1.26 | 1.05 | 1.55 | 2.16 | 1.70 | 0.86 | 1.53 | 1.61 | 1.28 | 1.69 | 1.44 | 1.50 | 1.18 | 1.24 | 0.76 |
| May 18, '44 | 4 | 1.05 | 0.88 | 6.13 | 7.11 | 7.05 | 3.12 | 23.2 | 11.4 | 8.36 | 2.61 | 11.1 | 7.30 | 8.21 | 37.1 | 12.2 | 5.29 | 10.5 | 1.58 | 1.31 | 1.31 | 1.35 | 1.40 | 3.23 | 3.19 |
| July 11, '44 | 4 | 0.70 | 0.70 | 2.93 | 3.92 | 3.83 | 2.28 | 8.32 | 3.38 | 4.63 | 4.49 | 2.75 | 2.65 | 5.07 | 11.5 | 2.99 | 10.9 | 6.95 | 2.03 | 1.37 | 1.60 | 1.56 | 0.95 | 2.70 | 2.22 |
| Sept. 12, '45 | 4 | 4.90 | 6.40 | 3.55 | 8.33 | 5.05 | 5.57 | 12.4 | 11.8 | 11.8 | 8.80 | 11.2 | 9.48 | 11.1 | 16.0 | 14.0 | 11.8 | 19.5 | 7.95 | 6.36 | 5.48 | 8.95 | 2.87 | 6.52 | 5.76 |

* Rates for each of the first six irrigations (August 28, 1941 through April 3, 1942) are for the time required for the depth of application indicated to enter the soil. Subsequently, from May 7, 1942 through July 30, 1943, the rate is an "average" obtained from a 4-inch irrigation after a 2-inch application had entered the soil. This "average" was either (a) the average rate fo... the first hour, or (b) where the rate was too high to obtain a 1-hour period, it was the rate for such period as water remained on the surface. On the last three irrigations (May 18, 194... through September 12, 1945) the 2-inch irrigation preceding rate measurement was not applied.

† This treatment maintained until August 25, 1943, the same as no. 16. The changes then contemplated were never completed.

Because of modifications that had to be made in the program, no valid comparison can be made between the sod treatments and any of the other treatments. It had been planned to space irrigations sufficiently close together to keep moisture always available to the shallow rooted sod, but since this could not be done the sod basins were given weekly supplemental sprinklings. This so changed the moisture regime as to make any comparisons of questionable validity.

A number of comparisons have been selected as pertinent and are shown in figures 3 to 7 inclusive. The actual infiltration rates varied widely from irrigation to irrigation because of variation in the amount of drying out of the soil which had preceded the irrigations (4, 6), because of the practice for a period of
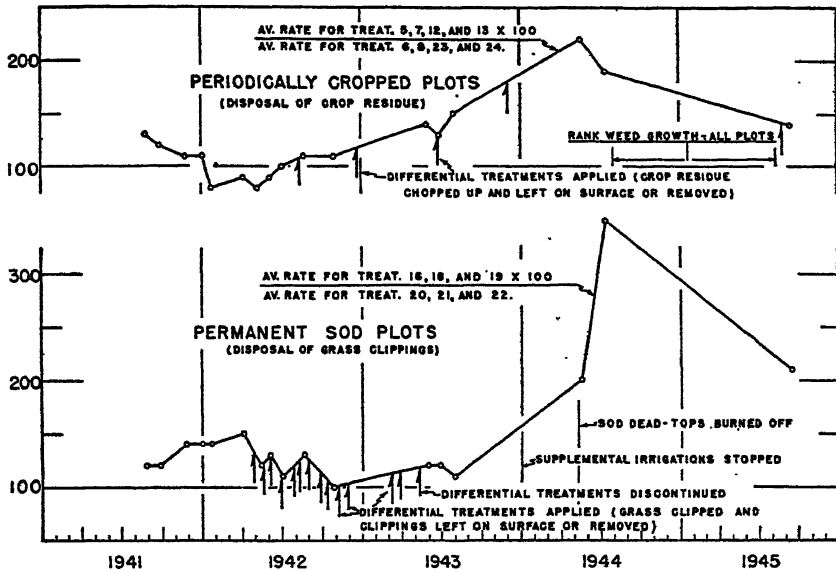


FIG. 3. INFILTRATION RATES WHERE CROP RESIDUE OR GRASS
CLIPPINGS WERE LEFT ON THE BASINS

Rates expressed as percentages of rates found for similar plots where crop residue or the grass clippings were removed. Dates when such differential treatments were applied are indicated.

applying "pre-irrigations," and because of differences in depth of irrigation and method of measurement. Therefore, the charts show, for each irrigation, the infiltration rate of a group of treatments as a percentage of the rate for another group for which a valid comparison can be made. The dates on which differential treatments were applied are indicated on the charts.

Figure 3 shows the effect of the method of crop residue disposal; that is, whether left on the basins or removed. Before the results are discussed, it should be noted that periods of wet weather here occur in winter and that the summers are dry. Most decay took place, therefore, in winter, and summer decay that would have resulted from wetting during irrigation was hindered by the fact that the litter

was removed from the basins during each irrigation. It is not surprising, then, that there was no appreciable response to organic matter in 1942. Thereafter, for the periodically cropped plots, there was a signicant improvement in infiltration rates where the crop residue was left in the basins.

With the permanent sod plots there was no evidence of improvement of infiltration rates due to leaving the grass clippings on the surface until after the sod had dried up and had burned off. There are two factors which would appear to have caused this. First, it was impractical to pick all clippings up from around the roots; and therefore both groups of treatments had sources of some organic matter. Second, on the plots where the clippings were left on the surface, these formed a dense mat. Such a mat could well shade the ground surface sufficiently
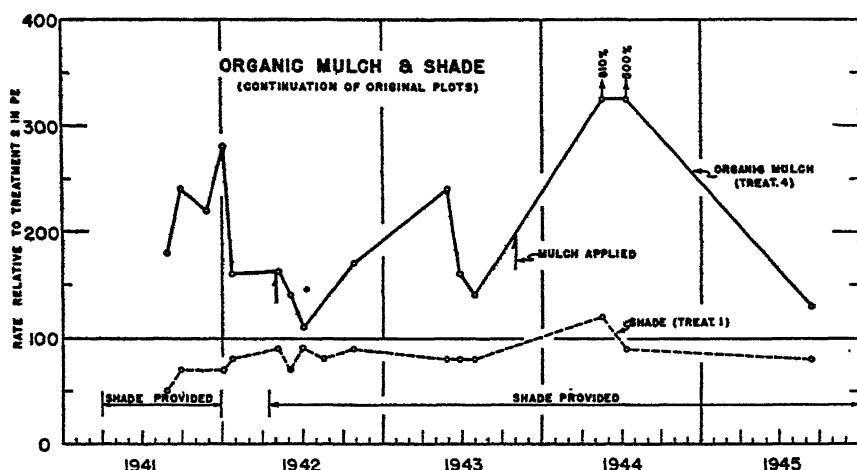


FIG. 4. INFILTRATION RATES FOR BASINS WHERE ORGANIC MULCH COVERED THE SURFACE OR WHERE THE SURFACE WAS SHADED

Rates expressed as percentages of rates for similar bare plots. Dates when differential treatments were applied are shown on this chart and on figure 2, from which these treatments are a continuation.

to decrease the drying out of the soil, and so adversely affect infiltration rates. It will be noted that the burning off of the sod in May 1944 effectively removed these variable factors from the comparison. Thereafter the plots showed a significant response to the differential treatments which had been applied from April 1942 to May 1943.

Figure 4 shows the effect of an organic mulch on basins bare of growing vegetation in comparison with bare basins on which there was no such mulch (figure 4 shows a continuation of original plots, and treatments begun in 1940 as shown on figure 2).[5] Here too, the surface applications of organic matter showed a marked effect on infiltration rates. The principal effect was found, however, after such

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[5] Figure 2 data corrected for pretreatment differences. This was not believed necessary for the later work, and would have added considerably to its complexity.

litter had been on the soil surface through a winter and had had ample opportunity for decay.

Figure 4 also shows the effect of shade alone (also a continuation of the original treatments—see figure 2). The shade provided allowed full ventilation. Prior to April 1942 the shade covers intercepted rain and therefore were removed in winter. In April 1942 louvre type covers were installed that admitted the rain but tended to break its impact. This factor would not tend to decrease infiltration rates. It will be noted, then, that shade alone resulted in effectively decreased infiltration rates. At one irrigation (May 18, 1944) there appears to be an inconsistency, but this might well have resulted from the inadequate care the plots were receiving at that time. From the evidence with the shade alone, it would appear that the influence of decaying organic matter on infiltration is most marked, since it must overcome the detrimental shading produced by the organic mulch.
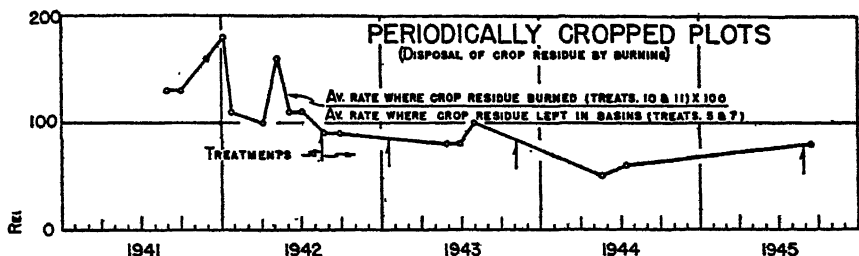


FIG. 5. INFILTRATION RATES IN PERIODICALLY CROPPED PLOTS WHERE CROP RESIDUE ON SURFACE WAS BURNED

Rates expressed as percentages of rates for similar plots where residue was not burned. Dates of burning are indicated.

Figure 5 compares burning of the crop residue and leaving such residue in the basins to decay. Burning resulted in significantly decreased infiltration rates in this comparison, being somewhat comparable to treatments where the crop residue was removed.

Figure 6 shows the effect of tillage, comparing cultivated treatments with similar treatments not cultivated. Figure 2 indicated that, at first, tillage benefitted infiltration rates only for the first irrigation following cultivation. Later, however, improvement was also noted in succeeding irrigations. In figure 6 it will be noted that any infiltration rate increases were absorbed by the preirrigations—during the period when the basins were given such a preirrigation before the measured irrigation. However, for the irrigation of July 11, 1944 infiltration rates were definitely higher, although no cultivation had preceded that irrigation. All in all, the data are not too conclusive, although certainly the principal effect of hand cultivation on infiltration rates was decidedly temporary in nature.

It must be noted that frequent cultivation is commonly believed to break down soil structure and so tend to cause decreased infiltration rates. Also, cultivation

with heavy vibrating implements and tractors has been shown to cause development of a cultivation pan in some soils (2, 3). With the infrequent hand cultivation in these experiments, no such factors were present, although there appeared to be a residual cultivation pan in the soil resulting from tillage practices used before the comprehensive plots were installed.

Figure 7 illustrates the effect of fertilizers infiltration rates. It has been shown elsewhere (1, 3) that any effect of such fertilizers depends on the buffer capacity
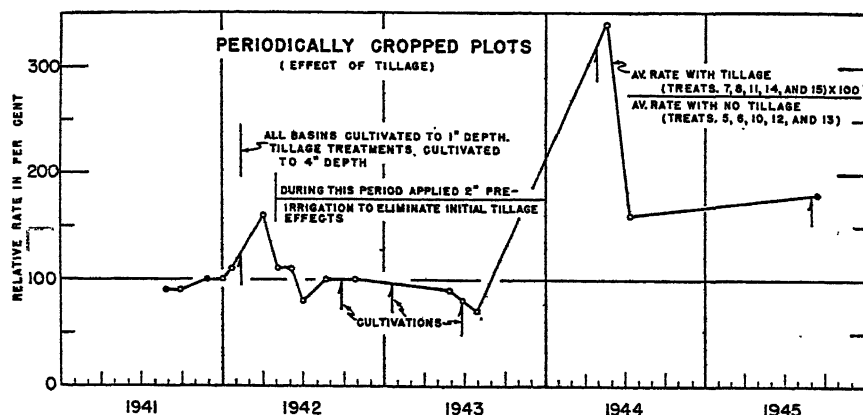


FIG. 6. INFILTRATION RATES IN PLOTS WHERE SOIL WAS CULTIVATED ON DATES INDICATED

Rates expressed as percentages of rates for similar plots which were not cultivated.
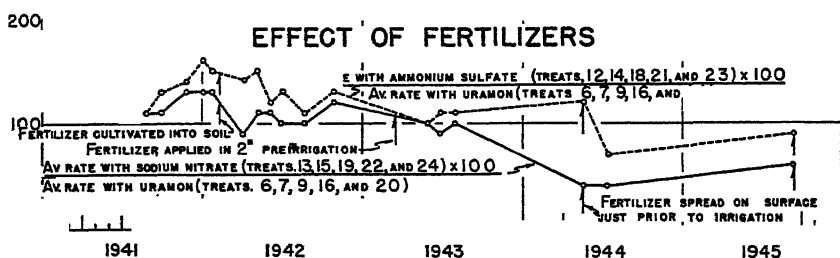


FIG. 7. INFILTRATION RATES FOR PLOTS FERTILIZED WITH AMMONIUM SULFATE AND SODIUM NITRATE

Rates expressed as percentages of rates for similar plots fertilized with Uramon. All plots were fertilized at the same time, as indicated, and each received 100 pounds N per application.

and the chemical constituents of the soil, on the chemical constituents of the irrigation water, and on the concentration of the fertilizer, which in turn is related to the method of application. Figure 7 shows that ammonium sulfate significantly reduced infiltration rates following the application on May 18, 1944, when the method was such as to provide greatest concentration at the surface crust. It has been shown (1, 3) that ammonium replaces calcium, with consequent soil dispersion, when the concentration is such that the soil becomes so acid as to prevent nitrification of the ammonia.

Sodium nitrate may cause dispersion and reduce infiltration rates by the replacement of calcium by sodium on the colloid (1). Decreased permeability was noted after the applications of March 1943 and May 18, 1944 and was greater than with ammonium sulfate.

## CONCLUSIONS

Organic matter applied to the surface or incorporated in the surface soil can, when it decays, cause a marked improvement in the structure of the soil, as shown by increases in the rate of water entry. This has been determined on a typical soil in a semiarid area where the organic matter contents of soils are normally extremely low. Findings under other environments might not necessarily agree.

Shade alone tends to cause a lowering of the rate of water entry into the soil, apparently because the surface soil does not dry out so much. The beneficial effects of decaying organic mulch apparently more than overcome the depressing effect of shade upon infiltration rates.

Hand cultivation results in a temporary increase in the rate of water entry into a soil. With the light infrequent cultivation employed, this increase frequently did not last for more than one 2-inch irrigation. The amount of compaction prior to cultivation may be an important factor in this regard, although these experiments were not designed to bring that point out.

With the irrigation water used (about 250 p.p.m. total solids with about 40 per cent of total cations as sodium), applications of ammonium sulfate and sodium nitrate at the rate of 100 pounds N per acre had little effect on rate of water entry if care was utilized to keep concentrations low. When applied so as to allow some concentration, sodium sulfate resulted in the greatest reduction of rate, and ammonium sulfate resulted in a somewhat lesser reduction.

Infiltration rates were reduced when a crop residue on the soil surface was burned.

The skimming of a ¼-inch crust from the surface of the soil did not materially affect the infiltration characteristics imparted to the plots by organic matter, cultivation, or shade. The influence of these factors, then, extended to greater depths.

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# DECARBOXYLATION RATE OF URONIC GROUPS CONTAINED IN SOIL ORGANIC MATTER, PLANT GUMS OF KNOWN CONSTITUTION, PLANT MATERIALS, AND MICROBIAL PRODUCTS[1]

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Polyuronides and uronic units are widely distributed in nature as products of plants, animals, and microorganisms. The encrusting hemicelluloses, ever present in plants, are uronic in part; pectin contains polygalacturonide; and some bacteria are known to produce polyuronide gums. Reasonably pure polyuronides such as lemon, cherry, and plum gum result from gummosis of trees. Natural plant mucilages such as those from *Plantago fastigiata* (1) and *Ulmus fulva* (6) yield uronic acids. Uronic acids have also been reported in soils (5, 13, 14).

When soil organic matter is treated with boiling 12 per cent hydrochloric acid according to the method described by Lefèvre and Tollens (8), carbon dioxide is liberated. The assumption that the carbon dioxide comes from the decarboxylation of uronic units is based on the finding that carboxyl groups other than uronic yield but small quantities of carbon dioxide. This cannot be taken as conclusive evidence that uronides occur in soil, though it is difficult not to believe that some uronic-bearing polysaccharides are continually being formed by microorganisms in soils as plant residues are decomposed and that these may be detected by the uronic determination.

If most of the $CO_2$ liberated from soil organic matter on boiling with 12 per cent HCl is assumed to originate from uronic groups, a considerable part of the soil organic carbon would appear to be uronic in nature. As much as 10 to 38 per cent of the total organic carbon has been reported to be uronic by Norman and Bartholomew (13); while Shorey and Martin (14), the first to analyze for the presence of uronides in soils, have reported 13 to 28 per cent; and Waksman and Reuszer (15), 6 to 32 per cent. Fuller, Bartholomew, and Norman (5) found similar quantities. Inasmuch as uronic groups do not characteristically appear alone but are usually in association with nonuronic carbohydrates, it is quite likely that a greater percentage of carbon may be involved in soil uronic substances than is indicated by these apparent uronic carbon figures.

In view of the ready availability of the major uronic constituents of normal plant materials to microorganisms, it is curious that such a large proportion of the soil organic carbon is uronic and that the amount reported to be in soils is so much greater than that of normal plant tissues or ordinary microbial tissues and products. Moreover, why should the percentage of apparent uronic carbon increase with increasing soil depth (5) and the probable greater degree of organic

matter decomposition?  Even during the course of biological decomposition of oat and rye straw, Norman (10) found that the uronic content changed but little, although as much as 50 per cent loss in total weight took place.

Although it has been repeatedly expressed that the apparent uronides in well-decomposed plant materials and soil organic matter have their origin in a portion of the hemicelluloses that resists biological attack (15), it is difficult to be reconciled to this view, since a large number of soil microorganisms are capable of rapidly destroying the hemicelluloses.  Inasmuch as microorganisms have been shown to synthesize polyuronide gums (7, 9, 12), it appears much more likely that the decomposition of plant polyuronides and the synthesis of microbial uronides take place concurrently and the loss of one more or less counterbalances the synthesis of the other, making it only appear that the polyuronides of the plant materials are being slightly attacked.  Quite likely, microbial synthesis, accompanied by the formation of resistant uronide-containing compounds, is responsible for the accumulation of apparent uronic groups in soils.  The fact that the usual method of uronic acid analysis was not designed to aid in distinguishing between uronides from different sources has not helped to clarify the situation.

There is good evidence that the rate of decarboxylation of uronic groups varies among various uronic-containing substances (2, 16).  This has led to the premise that the rate of decarboxylation of uronic groups can be used to classify and distinguish between the various uronic-bearing carbohydrates, thus furnishing evidence as to the nature and source of the $CO_2$-yielding constituents of soil organic matter.  With this in mind, the rate of decarboxylation of uronic groups found in polyuronide gums of known constitution, mature plant tissues, plant materials subjected to various periods of decomposition, bacterial gums, and soil organic matter was investigated.

## MATERIALS AND METHODS

The methods and apparatus used for the decarboxylation or uronic units in soils, plant gums, plant materials, and bacterial gums are described in an earlier study (2)    The $CO_2$ evolved was determined every 15 minutes for the first hour, then for $\frac{1}{2}$-, 1-, 2-$\frac{1}{2}$-, and 2-hour intervals to give a total of 7 hours.

The soils used in this investigation are described in an earlier paper (2).

The legumes used in the decomposition studies were cut at half-bloom stage, and the grasses were selected as the heads were beginning to emerge.  The straws were obtained immediately after thrashing.  The oak leaves, pine needles, and oak wood were collected just before frost in 1944.  The plant materials for decomposition were air-dried, cut into pieces $\frac{1}{4}$ to $\frac{1}{2}$ inch long, weighed into 10-gm. lots, and placed into wide-mouth pint bottles.  The oak wood was ground into fine shavings.  Each sample of plant material received 20 ml. of a suspension of soil organisms obtained by shaking 1 part fresh soil with 10 parts water for 4 minutes .  Additions of the clear supernatant liquid that developed upon standing a short time prevented any error that may have been caused by addition of small amounts of soil in suspension.  Water was added throughout

the decomposition period to keep the material well moistened but not saturated. Uronic analyses were made on the total residue from each bottle after culturing had continued for periods of 5, 10, 30, and 180 days.

Pectin was removed from 10-gm. samples of original plant materials by extraction with 0.5 per cent ammonium oxalate solution. After 4 hours of extraction at 80° C., the material was filtered through broadcloth, washed and re-extracted for an additional 20 hours with a second 500-ml. portion of extractant. The final washing, with water, was continued until no oxalate could be detected in the filtrate.

Since there is some evidence that oven-drying influences the yield of uronic carbon, air-dry samples were used. Moisture analyses were made on separate samples.

Polyuronide gums from pure cultures of *Sporocytophaga myxococcoides* and *Rhizobium trifolium* were produced by aerating inoculated liquid mineral nutrient solution containing finely ground filter paper as a carbon source for the former and sucrose for the latter organism. Aeration with sterilized air was continued until a maximum amount of gum was produced. The crude cytophaga gum was separated from the remaining cellulose fiber by filtering through broadcloth stretched over a 9-cm. Büchner funnel. The fiber was washed with cold water and again filtered on broadcloth. Both gums were centrifuged to remove some of the bacterial cells and other extraneous materials and precipitated by addition of 4 volumes of ethanol to 1 of gum solution. They were finally washed by dissolving in water and re-precipitating with additional portions of ethanol.

<center>RESULTS</center>

<center>*Soil organic matter*</center>

The rate of evolution of uronic carbon from various surface soils and subsoils is shown in table 1 along with figures for total carbon. The data show that between 10 and 25 per cent of the apparent uronic carbon of surface soil was liberated during the first 15 minutes of boiling, the first quarter hour being occupied in bringing the temperature to 135° C. Somewhat higher amounts, 15 to 30 per cent, were liberated from subsoils during the same interval. At the end of ¼ hours, between one-third and one-half of the total carbon evolved was liberated from both surface and subsoil. The rate of carbon evolution from the surface and subsoil of Clinton silt loam is shown in figure 1. The points on the curves represent mean rates of evolution of carbon during intervals of ¼ hour for the first hour and for additional intervals of ½, 1, 2½, and 2 hours. Without exception the most intense rate of evolution took place the first ¼ hour after boiling commenced. The rate appeared more intense for subsoil than surface soil. A rapid decline in rate of evolution took place immediately after the initial peak. This was characteristically followed by a rather slow but uniform reduction in the rate of liberation.

Inasmuch as the rate of evolution of carbon from subsoil changed very little the last 3 hours of boiling, it appears that the carbon may not come wholly from

uronic sources. It is not inconceivable that an error in the determination may be appreciable where subsoils are concerned, because of the very small amount of organic matter present. Surely no absolute value should be placed on figures obtained by this method. Far more important is the value of the general shape of the curves for comparative purposes.

TABLE 1

*Rate of evolution of apparent uronic carbon from various soils*

| SOIL | ORGANIC CARBON | CARBON EVOLVED PER HOUR PER GRAM ORGANIC CARBON | | | | | | | | URONIC C / ORGANIC C |
|------|------|------|------|------|------|------|------|------|------|------|
| | | Hours | | | | | | | | |
| | | 0.25 | 0.50 | 0.75 | 1.00 | 1.50 | 2.50 | 5.00 | 7.00 | |
| | *per cent* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *per cent* |
| *Surface horizon* | | | | | | | | | | |
| Clarion silt loam | 4.3 | 0.2 | 12.8 | 6.5 | 6.3 | 5.3 | 4.5 | 2.0 | 1.0 | 12.4 |
| Gloucester loam | 4.1 | 0.1 | 25.5 | 10.5 | 7.8 | 6.0 | 4.3 | 1.7 | 1.0 | 14.5 |
| Carrington loam | 4.0 | 1.1 | 17.3 | 8.0 | 6.2 | 5.9 | 5.0 | 2.4 | 1.1 | 14.6 |
| Williams stony loam | 3.8 | 0.4 | 9.5 | 6.8 | 6.0 | 5.4 | 5.2 | 3.3 | 1.7 | 14.9 |
| Bearden silty clay loam | 3.6 | 0.3 | 10.7 | 5.9 | 5.6 | 4.5 | 4.0 | 2.2 | 1.2 | 11.8 |
| Russell silt loam | 3.2 | 1.4 | 22.7 | 9.1 | 7.7 | 6.7 | 4.9 | 2.1 | 1.1 | 15.6 |
| Houston black clay | 2.0 | 0.5 | 7.5 | 3.7 | 3.7 | 3.5 | 3.4 | 2.8 | 1.9 | 11.8 |
| Clinton silt loam | 2.0 | 1.4 | 20.8 | 7.7 | 6.3 | 5.4 | 4.0 | 2.8 | 1.3 | 14.7 |
| Beaverton loam | 1.9 | 1.0 | 17.6 | 9.1 | 8.6 | 7.6 | 6.4 | 3.8 | 2.3 | 20.5 |
| Miami silt loam | 1.7 | 0.3 | 18.9 | 8.2 | 7.6 | 6.6 | 5.1 | 3.2 | 2.0 | 18.3 |
| Dewey silt loam | 1.1 | 1.1 | 25.2 | 9.0 | 8.9 | 6.9 | 6.1 | 4.2 | 3.1 | 22.8 |
| Norfolk silt loam | 1.0 | 1.0 | 9.1 | 5.9 | 5.0 | 4.1 | 2.6 | 1.2 | 0.7 | 8.5 |
| Portneuf silt loam | 0.8 | 1.1 | 19.5 | 6.5 | 6.5 | 6.0 | 5.7 | 4.0 | 2.9 | 19.6 |
| Mohave silty clay loam | 0.4 | 2.1 | 14.5 | 6.2 | 6.2 | 5.2 | 4.1 | 3.4 | 2.1 | 16.0 |
| *Subsoils* | | | | | | | | | | |
| Clarion | 0.9 | 2.0 | 20.6 | 6.9 | 5.4 | 5.4 | 5.2 | 4.8 | 4.1 | 22.2 |
| Gloucester | 0.4 | 1.1 | 36.5 | 11.4 | 8.0 | 5.1 | 4.0 | 3.2 | 2.3 | 19.2 |
| Carrington | 0.4 | 2.3 | 40.7 | 10.7 | 8.5 | 8.6 | 6.4 | 5.0 | 1.6 | 25.2 |
| Russell | 0.3 | 2.7 | 31.0 | 9.0 | 7.8 | 6.5 | 4.8 | 3.6 | 1.2 | 20.0 |
| Clinton | 0.3 | 3.5 | 33.3 | 10.5 | 5.3 | 3.0 | 3.5 | 4.0 | 2.4 | 18.6 |
| Miami | 0.3 | 5.9 | 44.1 | 7.4 | 5.9 | 5.9 | 4.0 | 3.1 | 2.6 | 20.0 |
| Norfolk | 0.3 | 6.2 | 45.6 | 15.2 | 12.1 | 7.6 | 6.8 | 4.7 | 4.2 | 30.1 |

Data in table 1, in addition, indicate that though the organic carbon in surface soils varied tenfold, the proportion of uronic to total organic carbon varied but little Moreover, the proportion of uronic to organic carbon seemed to be independent of the amount of organic carbon in the original sample. A greater percentage of the organic carbon appeared to be uronic in nature in subsoils than in surface soils.

*Plant gums*

In an attempt to obtain additional information as to the nature of $CO_2$-yielding constituents of soils, the rate of $CO_2$ evolution from pure polyuronides of known constitution was followed and compared with that from soils. The peak rate of evolution of uronic carbon from plant gums took place during the second 15-minute period of boiling rather than the first period as with soils (see figure 2). After $1\frac{1}{4}$ hours of boiling about one-third of uronic units of kelgum and gum arabic and about two-thirds of the units of pectin and mesquite gum had decarboxylated. The gums are shown in figure 2 to decarboxylate at two different rates.
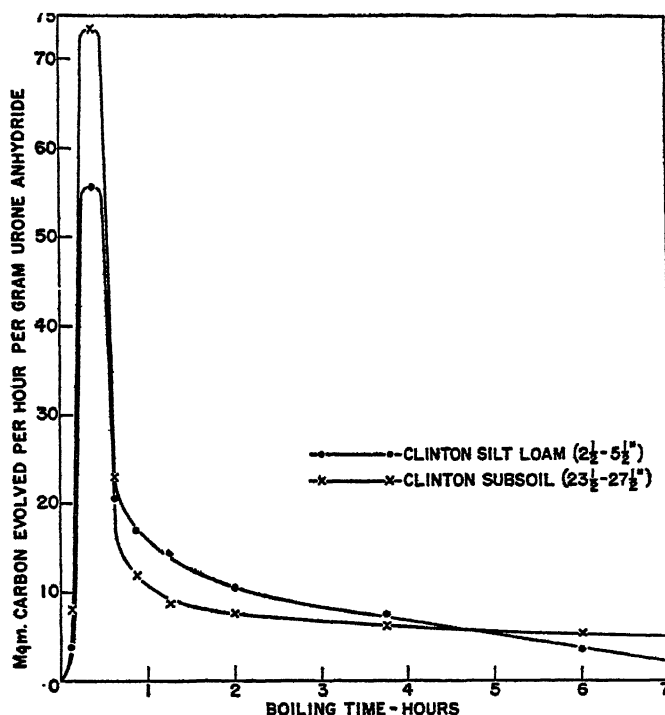


FIG. 1. RATE OF EVOLUTION OF APPARENT URONIC CARBON FROM CLINTON SILT LOAM

The rate of carbon evolution from pectin and mesquite gum appears more like that of soils than that of kelgum and gum arabic.

*Plant materials*

The nature of the uronic-bearing carbohydrates of plant materials might be expected to have some influence on the nature of the apparent uronic constituents of soil organic matter. The rate of decarboxylation of some natural plant materials that may contribute to soil organic matter is shown in table 2. Except for the legumes and the oak leaves and wood, the most intense rate of $CO_2$

evolution took place during the first 15 minutes after the reaction temperature had reached 135° C. The rate of decarboxylation of uronic units of timothy,
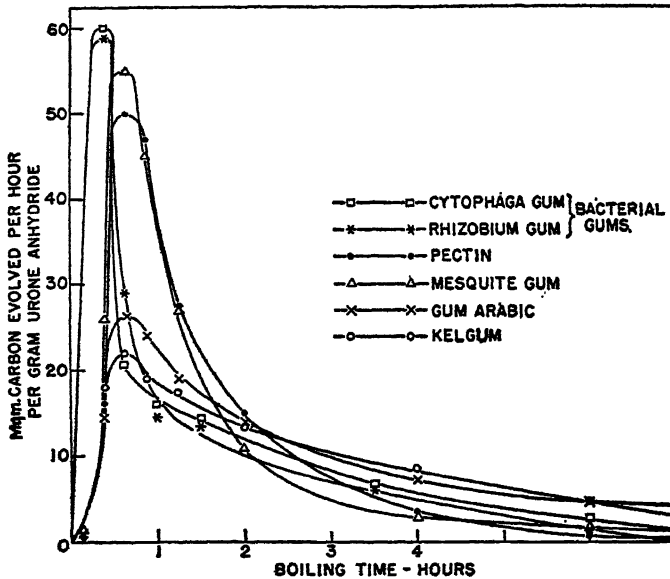


FIG. 2. DECARBOXYLATION RATE OF URONIC UNITS OF SOME PLANT AND BACTERIAL GUMS
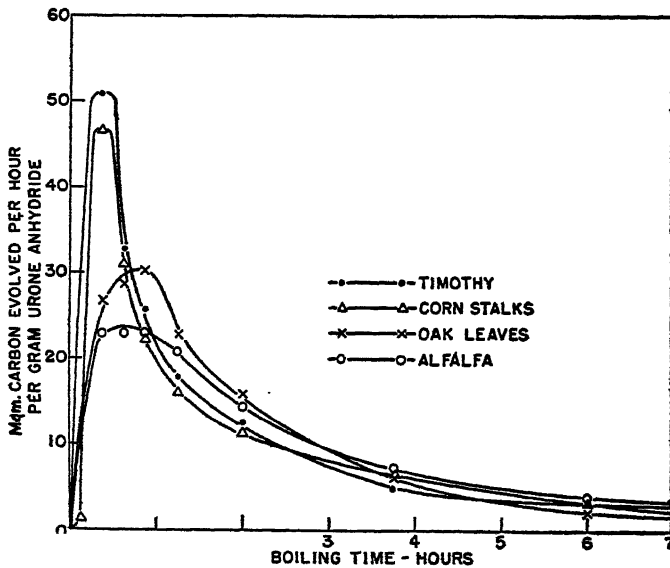


FIG. 3. DECARBOXYLATION RATE OF URONIC UNITS OF SOME NATURAL PLANT MATERIALS

corn stalks, oak leaves, and alfalfa is shown in figure 3. Two general types of curves are exhibited just as with plant gums. The rate of carbon evolution from the legumes and oak materials was greatest sometime shortly after 30 minutes

of boiling.   On the other hand, the rate of evolution of carbon from the grasses, straws, etc., was greatest during the first 15 minutes of boiling, just as with soil organic matter.

In general, the amount of uronic carbon in plant materials is not large.   Young plants usually contain greater quantities of polyuronides than mature plants. The uronide content of different types of plants may also vary considerably. Data in table 2 indicate that the legumes at half-bloom stage yielded two to three times as much uronic carbon per unit of total carbon as did the grasses and other plant materials at about the same stage of maturity.

The two major uronic-bearing carbohydrates in natural plant materials are pectin and polyuronide hemicelluloses.   Better to study the nature of these two

TABLE 2

*Rate of decarboxylation of uronic units of some natural plant materials*

| PLANT MATERIAL | ORGANIC CARBON | CARBON EVOLVED PER HOUR PER GRAM ORGANIC CARBON | | | | | | | | URONIC C TOTAL C |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Hours | | | | | | | | |
| | | 0.25 | 0.50 | 0.75 | 1.00 | 1.50 | 2.50 | 5.00 | 7.00 | |
| | *per cent* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *per cent* |
| Alfalfa | 48.1 | 0.1 | 5.5 | 5.5 | 5.5 | 5.0 | 3.5 | 1.8 | 0.9 | 9.9 |
| Red clover | 41.4 | 0.0 | 6.8 | 7.0 | 7.2 | 6.0 | 4.3 | 1.9 | 0.7 | 11.3 |
| Bluegrass | 45.6 | 0.1 | 4.3 | 3.2 | 3.3 | 2.3 | 1.9 | 1.0 | 0.4 | 5.3 |
| Millet (young) | 39.4 | 0.3 | 5.8 | 4.1 | 3.0 | 2.5 | 1.9 | 1.0 | 0.5 | 5.8 |
| Millet (mature) | 42.6 | 0.1 | 4.0 | 3.3 | 2.2 | 1.7 | 1.1 | 0.6 | 0.4 | 3.9 |
| Orchard grass | 44.0 | 0.1 | 4.2 | 4.0 | 2.9 | 2.0 | 1.3 | 0.6 | 0.3 | 4.4 |
| Reed canary grass | 43.4 | 0.1 | 4.8 | 3.1 | 2.2 | 1.5 | 1.1 | 0.6 | 0.4 | 3.8 |
| Rye grass | 44.9 | 0.2 | 4.3 | 2.7 | 1.6 | 1.3 | 0.9 | 0.4 | 0.3 | 3.3 |
| Timothy hay | 46.5 | 0.1 | 4.3 | 2.8 | 2.2 | 1.5 | 1.1 | 0.4 | 0.3 | 3.5 |
| Grass roots | 46.3 | 0.1 | 6.4 | 4.0 | 2.9 | 2.1 | 1.4 | 0.8 | 0.3 | 5.0 |
| Corn stalks | 48.6 | 0.1 | 5.3 | 3.9 | 3.5 | 2.4 | 1.6 | 0.8 | 0.4 | 5.3 |
| Oat straw | 47.4 | 0.1 | 3.5 | 2.6 | 1.6 | 1.2 | 0.8 | 0.5 | 0.4 | 3.2 |
| Wheat straw | 45.9 | 0.1 | 4.3 | 3.0 | 2.5 | 1.8 | 1.2 | 0.5 | 0.4 | 4.0 |
| Pine needles | 52.1 | 0.0 | 6.7 | 5.7 | 5.7 | 4.5 | 2.9 | 1.0 | 0.5 | 7.7 |
| Oak leaves | 46.3 | 0.0 | 4.3 | 5.3 | 5.7 | 4.2 | 2.9 | 1.1 | 0.5 | 7.6 |
| Oak wood | 43.0 | 0.2 | 1.4 | 3.2 | 3.4 | 2.9 | 1.7 | 0.6 | 0.3 | 4.3 |

constituents, sixteen different plant materials were extracted with hot 0.5 per cent ammonium oxalate to remove the pectin.   The decarboxylation rate of the uronic units of the plant residues is shown in table 3.   For the most part, the carbon evolved from this residue comes from the polyuronide hemicellulose. In general, the rate of decarboxylation of the residue was uniformly decreased throughout the boiling period as a result of the extraction.   Thus the character-istic decarboxylation rate of the uronic units of the plant pectins and the poly-uronide hemicelluloses may be considered to be very similar.   Pine needles lost the greatest amount of uronic carbon upon extraction (about 75 per cent), while oak wood lost no uronic carbon.   About 50 per cent of the uronic carbon of the grasses and legumes was extractable with the ammonium oxalate solution.

<div align="center">TABLE 3</div>

*Rate of decarboxylation of uronic units of ammonium-oxalate–extracted plant materials*

| PLANT MATERIAL | CARBON EVOLVED PER HOUR PER GRAM ORIGINAL CARBON | | | | | | | | URONIC C / TOTAL C |
|---|---|---|---|---|---|---|---|---|---|
| | Hours | | | | | | | | |
| | 0.25 | 0.50 | 0.75 | 1.00 | 1.50 | 2.50 | 5.00 | 7.00 | |
| | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | per cent |
| Alfalfa | 0.1 | 0.9 | 3.4 | 3.6 | 3.1 | 1.9 | 1.0 | 0.3 | 4.9 |
| Red clover | 0.1 | 1.6 | 2.9 | 2.9 | 2.6 | 2.0 | 0.8 | 0.3 | 4.4 |
| Bluegrass | 0.1 | 2.1 | 1.9 | 1.7 | 1.2 | 0.9 | 0.4 | 0.2 | 2.6 |
| Millet (young) | 0.2 | 3.0 | 2.9 | 2.1 | 1.5 | 1.2 | 0.6 | 0.3 | 3.7 |
| Millet (mature) | 0.3 | 3.3 | 2.4 | 1.7 | 1.3 | 0.9 | 0.5 | 0.3 | 3.1 |
| Orchard grass | 0.1 | 2.8 | 1.9 | 1.7 | 1.4 | 0.9 | 0.3 | 0.2 | 2.7 |
| Reed canary grass | 0.1 | 3.0 | 2.8 | 1.6 | 1.1 | 0.7 | 0.4 | 0.2 | 2.6 |
| Rye grass | 0.1 | 2.5 | 1.3 | 1.1 | 1.0 | 1.0 | 0.4 | 0.3 | 2.5 |
| Timothy hay | 0.1 | 2.7 | 2.4 | 1.6 | 1.2 | 0.7 | 0.4 | 0.2 | 2.7 |
| Corn stalks | 0.1 | 3.5 | 3.1 | 2.7 | 1.8 | 1.1 | 0.5 | 0.2 | 3.6 |
| Wheat straw | 0.0 | 3.2 | 2.6 | 2.1 | 1.6 | 0.9 | 0.3 | 0.3 | 3.0 |
| Pine needles | 0.1 | 1.5 | 2.0 | 2.0 | 1.6 | 0.9 | 0.3 | 0.3 | 1.9 |
| Oak leaves | 0.1 | 3.1 | 3.5 | 3.4 | 2.8 | 1.8 | 0.6 | 0.2 | 5.0 |
| Oak wood | 0.1 | 1.5 | 2.0 | 3.9 | 3.4 | 1.8 | 0.6 | 0.3 | 4.3 |

<div align="center">TABLE 4</div>

*Weight of total residue and uronic carbon of plant materials decomposed for various periods of time by soil organisms*

<div align="center">(Expressed on basis of 100 gm. of original plant material)</div>

| PLANT MATERIAL | WEIGHT OF RESIDUE | | | | | WEIGHT OF URONIC CARBON | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Days | | | | Original | Days | | | |
| | 5 | 10 | 30 | 180 | | 5 | 10 | 30 | 180 |
| | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. |
| Alfalfa | 64.0 | 59.8 | 45.9 | 33.2 | 5.018 | 1.984 | 1.654 | 1.149 | 1.448 |
| Red clover | 70.3 | .... | 51.0 | 42.9 | 5.047 | 2.194 | ..... | 2.308 | 2.324 |
| Bluegrass | 80.0 | .... | 52.9 | 39.7 | 2.453 | 1.847 | ..... | 1.678 | 1.701 |
| Millet (mature) | 84.2 | 71.6 | 56.9 | 41.0 | 1.879 | 1.495 | 1.346 | 1.165 | 1.358 |
| Orchard grass | 78.9 | 72.4 | 52.3 | 34.4 | 2.107 | 1.391 | 1.358 | 1.090 | 0.907 |
| Reed canary grass | 84.3 | 78.4 | 62.5 | 33.7 | 1.852 | 1.492 | 1.304 | 1.111 | 0.904 |
| Rye grass | 80.8 | 74.4 | 54.3 | 28.3 | 1.639 | 1.399 | 1.306 | 1.053 | 0.772 |
| Timothy hay | 81.2 | 75.0 | 48.8 | 29.9 | 1.836 | 1.445 | 1.349 | 0.848 | 0.799 |
| Corn stalks | 89.2 | .... | 70.6 | 46.7 | 2.555 | 2.110 | ..... | 1.748 | 1.322 |
| Wheat straw | 95.5 | 93.8 | 87.9 | 59.3 | 1.939 | 1.643 | 1.519 | 1.457 | 1.122 |
| Roots (millet) | 94.4 | .... | 84.6 | 59.0 | 2.312 | 2.131 | ..... | 2.029 | 1.365 |
| Oak leaves | 98.4 | 95.6 | 90.8 | 76.9 | 3.969 | 4.017 | 3.986 | 4.129 | 3.260 |
| Oak wood | 98.6 | 96.5 | 94.9 | 92.6 | 1.973 | 2.093 | 2.043 | 2.041 | 2.035 |

Changes in the quantity and rate of decarboxylation of uronic units of natural plant materials were followed during the decomposition in bottles with a mixed soil flora in an attempt to ascertain what might be expected to happen to the vast

## TABLE 5

*Rate of decarboxylation of uronic groups of plant materials at various stages of decomposition*

| MATERIAL | TIME DECOM-POSED | CARBON EVOLVED PER HOUR PER GRAM TOTAL CARBON | | | | | | | | URONIC C / TOTAL C |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Hours | | | | | | | | |
| | | 0.25 | 0.50 | 0.75 | 1.00 | 1.50 | 2.50 | 5.00 | 7.00 | |
| | days | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | mgm. | per cent |
| Alfalfa | 5 | 0.1 | 2.8 | 2.3 | 2.1 | 1.6 | 1.3 | 0.7 | 0.3 | 3.7 |
| | 10 | 0.1 | 2.5 | 1.9 | 1.7 | 1.4 | 1.1 | 0.5 | 0.2 | 3.1 |
| | 30 | 0.1 | 1.7 | 1.3 | 1.0 | 1.0 | 0.8 | 0.4 | 0.2 | 2.1 |
| | 180 | 0.1 | 6.9 | 1.4 | 1.1 | 1.1 | 0.6 | 0.3 | 0.1 | 2.7 |
| Red clover | 5 | 0.1 | 4.5 | 2.4 | 2.4 | 2.2 | 1.9 | 0.8 | 0.5 | 4.9 |
| | 30 | 1.0 | 13.3 | 2.2 | 1.8 | 1.5 | 1.4 | 0.5 | 0.3 | 5.2 |
| | 180 | 0.1 | 14.5 | 2.8 | 1.9 | 1.3 | 0.9 | 0.7 | 0.2 | 5.2 |
| Blue grass | 5 | 0.1 | 4.2 | 2.4 | 1.9 | 1.6 | 1.4 | 0.7 | 0.5 | 4.1 |
| | 30 | 0.2 | 10.3 | 1.5 | 1.0 | 0.9 | 0.7 | 0.4 | 0.2 | 3.4 |
| | 180 | 0.1 | 10.7 | 1.6 | 1.1 | 0.8 | 0.5 | 0.4 | 0.2 | 3.4 |
| Millet (mature) | 5 | 0.1 | 3.6 | 2.1 | 2.0 | 1.1 | 1.0 | 0.5 | 0.2 | 3.1 |
| | 10 | 0.1 | 3.5 | 2.1 | 1.8 | 1.0 | 0.7 | 0.4 | 0.2 | 2.8 |
| | 30 | 0.1 | 3.5 | 1.7 | 1.5 | 0.9 | 0.7 | 0.3 | 0.2 | 2.4 |
| | 180 | 0.7 | 9.9 | 1.1 | 0.7 | 0.5 | 0.5 | 0.2 | 0.2 | 2.8 |
| Orchard grass | 5 | 0.1 | 3.8 | 2.3 | 1.7 | 1.2 | 0.8 | 0.4 | 0.2 | 2.9 |
| | 10 | 0.1 | 3.4 | 2.4 | 1.7 | 1.2 | 0.8 | 0.4 | 0.2 | 2.8 |
| | 30 | 0.1 | 3.2 | 1.5 | 1.4 | 0.9 | 0.6 | 0.3 | 0.2 | 2.3 |
| | 180 | 0.2 | 4.3 | 1.1 | 0.8 | 0.5 | 0.4 | 0.3 | 0.1 | 1.9 |
| Reed canary grass | 5 | 0.1 | 3.9 | 2.4 | 1.7 | 1.2 | 0.8 | 0.5 | 0.3 | 3.1 |
| | 10 | 0.1 | 2.7 | 2.2 | 1.5 | 1.2 | 0.0 | 0.4 | 0.2 | 2.7 |
| | 30 | 0.1 | 2.7 | 1.5 | 1.1 | 1.1 | 0.7 | 0.4 | 0.2 | 2.3 |
| | 180 | 0.1 | 2.7 | 1.0 | 0.8 | 0.6 | 0.5 | 0.2 | 0.2 | 1.8 |
| Rye grass | 5 | 0.2 | 3.5 | 2.1 | 1.5 | 1.1 | 0.7 | 0.4 | 0.3 | 2.8 |
| | 10 | 0.1 | 3.1 | 2.4 | 1.5 | 1.0 | 0.6 | 0.4 | 0.3 | 2.6 |
| | 30 | 0.1 | 2.5 | 1.4 | 1.1 | 1.0 | 0.6 | 0.3 | 0.2 | 2.1 |
| | 180 | 0.1 | 3.3 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 | 1.4 |
| Timothy hay | 5 | 0.1 | 3.2 | 2.1 | 1.9 | 1.1 | 0.9 | 0.4 | 0.3 | 2.8 |
| | 10 | 0.1 | 2.4 | 2.4 | 2.0 | 1.2 | 0.8 | 0.4 | 0.2 | 2.6 |
| | 30 | 0.1 | 1.7 | 0.9 | 0.8 | 0.8 | 0.5 | 0.3 | 0.1 | 1.6 |
| | 180 | 0.1 | 2.7 | 1.0 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 1.5 |
| Grass roots | 5 | 0.1 | 5.7 | 3.4 | 2.3 | 2.0 | 1.4 | 0.7 | 0.4 | 4.8 |
| | 30 | 0.1 | 6.7 | 3.1 | 2.3 | 1.7 | 1.3 | 0.7 | 0.4 | 4.5 |
| | 180 | 0.1 | 5.0 | 2.1 | 1.7 | 1.2 | 0.9 | 0.5 | 0.3 | 3.3 |
| Corn stalks | 5 | 0.1 | 3.9 | 3.0 | 2.2 | 2.0 | 1.5 | 0.7 | 0.4 | 4.3 |
| | 30 | 0.1 | 4.1 | 2.7 | 2.0 | 1.4 | 1.0 | 0.6 | 0.3 | 3.6 |
| | 180 | 0.0 | 4.9 | 2.0 | 1.3 | 1.0 | 0.6 | 0.3 | 0.2 | 2.5 |

TABLE 5—*Continued*

| MATERIAL | TIME DECOM-POSED | CARBON EVOLVED PER HOUR PER GRAM TOTAL CARBON | | | | | | | | URONIC C / TOTAL C |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Hours | | | | | | | | |
| | | 0.25 | 0.50 | 0.75 | 1.00 | 1.50 | 2.50 | 5.00 | 7.00 | |
| | *days* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *per cent* |
| Wheat straw | 5 | 0.1 | 3.5 | 2.5 | 1.9 | 1.5 | 0.9 | 0.5 | 0.2 | 3.2 |
| | 10 | 0.1 | 3.0 | 2.4 | 1.9 | 1.5 | 0.8 | 0.4 | 0.2 | 2.7 |
| | 30 | 0.1 | 2.8 | 2.2 | 1.9 | 1.4 | 0.8 | 0.4 | 0.2 | 2.8 |
| | 180 | 0.0 | 2.6 | 1.8 | 1.3 | 1.0 | 0.6 | 0.3 | 0.2 | 2.2 |
| Oak leaves | 5 | 0.2 | 5.3 | 5.4 | 5.5 | 4.1 | 2.8 | 1.2 | 0.5 | 7.7 |
| | 10 | 0.2 | 4.8 | 5.6 | 5.2 | 4.0 | 2.8 | 1.2 | 0.5 | 7.8 |
| | 30 | 0.1 | 5.5 | 5.5 | 5.2 | 4.3 | 2.9 | 1.3 | 0.6 | 8.0 |
| | 180 | 0.1 | 6.4 | 4.0 | 3.8 | 2.8 | 2.0 | 1.0 | 0.4 | 6.3 |
| Oak wood | 5 | 0.2 | 1.7 | 3.2 | 3.4 | 3.1 | 1.8 | 0.8 | 0.3 | 4.6 |
| | 10 | 0.1 | 1.0 | 3.1 | 3.8 | 3.5 | 1.4 | 0.6 | 0.3 | 4.5 |
| | 30 | 0.1 | 1.8 | 3.1 | 3.5 | 3.2 | 1.6 | 0.6 | 0.4 | 4.5 |
| | 180 | 0.1 | 2.8 | 3.1 | 2.3 | 2.5 | 1.6 | 0.7 | 0.3 | 4.5 |

amount of uronic carbon that is subjected to decomposition each year in soils. The total weight of residue and uronic carbon after decomposition had continued 5, 10, 30, and 180 days is given in table 4. Generally the percentage loss of uronic carbon exceeded that of the total plant material during the first 10 days of decomposition, whereas at the end of 180 days the reverse was true. The apparent increase in uronic carbon of some plant materials, as alfalfa, red clover, bluegrass and millet (mature), that took place sometime after 30 days of incubation is one of the significant findings of the decomposition investigation.

The rate of decarboxylation of uronic groups of plant materials at various stages of decomposition is shown in table 5. The data indicate that the percentage of uronic units decarboxylated at any one time during the determination was altered little the first 30 days of decomposition. After 180 days of decomposition, however, the rate of decarboxylation of the residue was much more intense the first 15 minutes of boiling than before. In order to demonstrate more clearly the rate of decarboxylation of the plant residues as a result of decomposition, the milligrams of carbon evolved per hour per gram of urone anhydride of orchard grass is plotted in figure 4. The decarboxylation curves for the plant residues appear to become more like those of soils as decomposition increases. After 180 days of incubation the plant residue curves are nearly identical to the soil curves.

To follow the changes in the nature of the plant material as a result of decomposition in soil, virgin Leetonia sandy loam was sampled and apparent uronic carbon determined at different depths in the profile. The mor layer ($\frac{1}{2}$ — 0 inches) was composed mostly of partly decomposed leaves and fine roots, the main structures of which were almost intact. The organic matter in the lower part of this

layer, however, contained much well-disintegrated and poorly recognizable plant tissues. Table 6 shows that the proportion of apparent uronic carbon to total organic carbon of the partly decomposed mor layer was not unlike that found in other partly decomposed plant material. Furthermore, this proportion increased with depth and probable more extensive decomposition. Figure 5 shows that the rate of decarboxylation of the organic matter at increasing depths
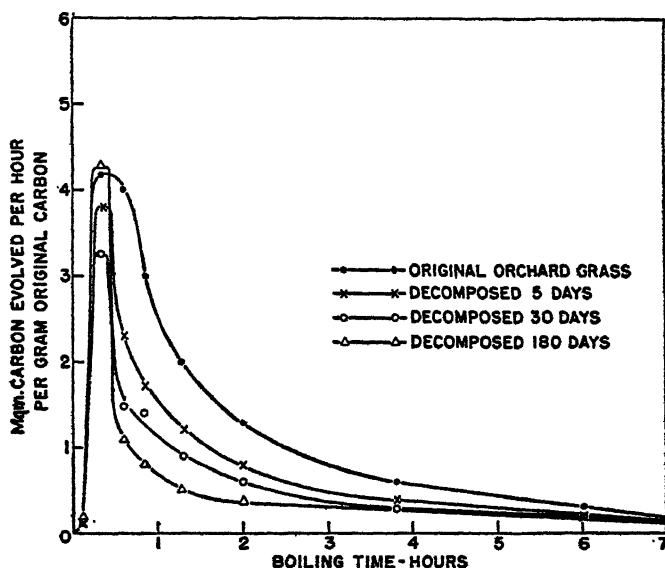


FIG. 4. DECARBOXYLATION RATE OF URONIC UNITS OF ORCHARD GRASS AT DIFFERENT STAGES OF DECOMPOSITION

TABLE 6

*Distribution of apparent uronic carbon in Leetonia sandy loam (podzol) profile*

| DEPTH | HORIZON | ORGANIC CARBON | CARBON EVOLVED / TOTAL C | URONIC CARBON / TOTAL C |
|---|---|---|---|---|
| *inches* | | *per cent* | *mgm./gm.* | *per cent* |
| $\frac{1}{2}$-0 | $A_0$ | 21.3 | 10.6 | 6.4 |
| $\frac{1}{4}$-0 | $A_1$ | 9.8 | 12.1 | 7.3 |
| 0-1 | $A_2$ | 2.0 | 13.2 | 7.9 |
| 1-3 | $B_{2-1}$ | 5.7 | 18.5 | 11.1 |
| 3-13 | $B_{2-2}$ | 2.0 | 29.1 | 17.5 |

followed the same general trend as did the isolated plant materials during the course of decomposition.

*Bacterial gums*

Some soil bacteria have been shown to produce polysaccharide gums containing uronic groups. Such gums are believed to contribute substantially to the uronic

units in soil organic matter.   The extent of the contribution from this source
has not been well established.   The decarboxylation rate of uronic carboxyl from
*S. myxococcoides* and *R. trifolium* gum may be seen in figure 2.   The striking
similarity in the rate at which uronic units of bacterial gums and soil organic
matter decarboxylate in this investigation lends support to the assumption that
the uronic content of soil organic matter is microbially derived.   About 22 per
cent of the uronic carbon was evolved the first 15 minutes of boiling and more
than 40 per cent appeared after boiling 45 minutes.   The total uronic acid an-
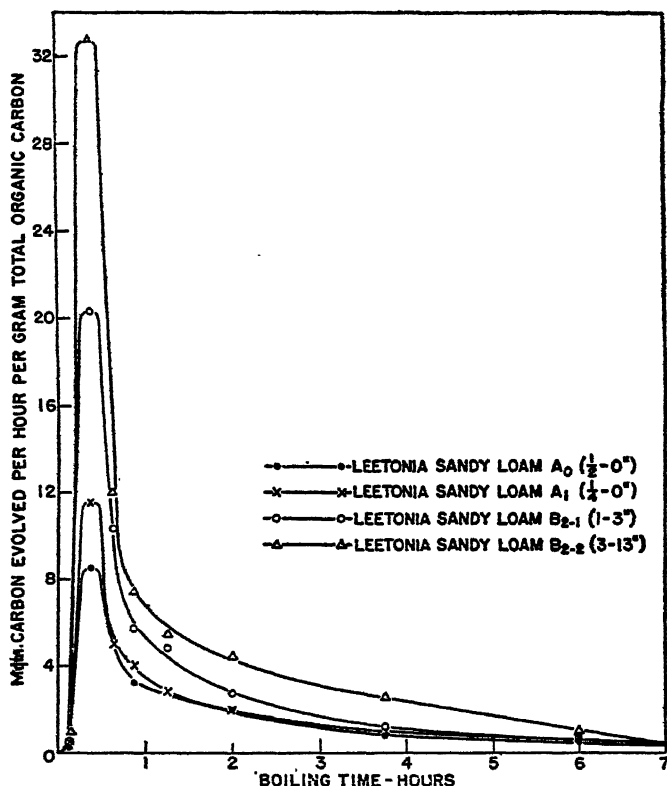


FIG. 5. RATE OF EVOLUTION OF CARBON FROM APPARENT URONIC UNITS OF LEETONIA FINE
SANDY LOAM AT DIFFERENT DEPTHS

hydride contained in the crude *Cytophaga* and *Rhizobium* gum was 8.9 and 7.5
per cent, respectively, while the total carbon content for the two gums was 30.3
and 35.3 per cent, respectively.

### DISCUSSION

Further evidence has been furnished by these investigations that the $CO_2$
evolved from soils when boiled with 12 per cent hydrochloric acid solution comes
from the decarboxylation of uronic units.   The determination of the decarboxyl-

ation rate of uronic groups has proved very helpful in furnishing this evidence. In comparing the rate of carbon evolution from apparent uronic units of soils to that of pure polyuronides of known constitution, natural plant materials, and bacterial polysaccharides, the general shape of rate curves was found to be similar. The rate of $CO_2$ evolution from nonuronic substances was shown in previous studies (2, 5, 16) to be rather uniform throughout the determination and quite unlike that from uronic groups. As decomposition progressed in natural plant materials the rate of carbon evolution from the residues during the uronic determination became progressively more like that from soil organic matter, until after 180 days of decomposition the two materials decarboxylated at nearly identical rates.

This evidence, in addition to the findings that, first, no other carboxyl group yields $CO_2$ except in small quantities by the uronic determination (2, 5, 13, 16) and, second, changes in temperature, acid concentration, and additions of reducing substances influenced very similarly the rate of decarboxylation of apparent uronic units of soils and uronic units of known polysaccharides (2), makes it seem certain that most of the $CO_2$ evolved from soil organic matter during the uronic determination comes from the decarboxylation of uronic units.

The characteristic changes in the rate of decarboxylation of the uronic units that accompany the decomposition offer another method for determining the nature and degree of decomposition of plant and compost materials. The rapid decrease in quantity of uronic acid anhydride that takes place during the early stages of decomposition may also be useful in determining the stage of plant decomposition. The degree of retting (rotting) of hemp, for example, was shown to be closely correlated with the degree of uronic destruction (4). Uronic carboxy is relatively easily determined, and the method of determination appears to be almost specific for uronic groups.

It appears that the specific nature of the uronic groupings exerts less influence on the rate of decarboxylation of the uronic units than the general structure or architecture of the uronide-bearing carbohydrates. Even though the uronic anhydride of both gum arabic and mesquite gum is glucuronic, the two decarboxylate at dissimilar rates. The rate of $CO_2$ evolution from the former was similar to that from kelgum, a mannuronide-containing polysaccharide. Mesquite gum, on the other hand, decarboxylated at a rate very like the polygalacturonide of lemon pectin.

The possibility that uronides in soil organic matter originate from microbial products appears quite likely. Since the uronic-bearing carbohydrates of plant tissues are readily available to attack (3) and complete destruction by soil microorganisms, plant-derived uronides cannot be expected to exist as such very long in productive soils. During the very early stages of decomposition of plant materials the uronic content was shown to suffer extensive loss. As decomposition progressed, however, the loss of the total residue exceeded that of the uronic units, and as the material became more extensively decomposed, only very small losses took place; moreover, in some instances the amount of uronic carbon actually increased. Inasmuch as soil bacteria have been shown to produce

uronide-bearing polysaccharides, the increase in uronic carbon of the well-decomposed plant residues was probably due to biological synthesis. Additional evidence that uronic units of soil organic matter arise from microbial products comes from the finding that the decarboxylation rate of apparent uronic units of soils more closely resembles that of uronic units of bacterial gums than any other uronide.

Although it has been shown that bacterial polysaccharides are utilized for microbial growth, it has not been demonstrated that the uronic units are directly attacked. It is conceivable that the uronic units of these complex bacterial gums are so arranged in the polysaccharide that they may resist attack while associated sugar units are utilized, leaving a uronide-rich residue. On the other hand, if microbially derived uronic groups are relatively available to attack by soil organisms they must be temporarily immobilized, at least, by association or combination with some other organic group or groups. The possibility that the uronidase enzymes may be partly inactivated by absorption on the soil colloids, as organic matter becomes more highly decomposed, must always be considered. The susceptibility of uronidases to this means of inactivation is not known. The reason for the apparent accumulation of uronic units in soils is still a matter of speculation.

With additional evidence favoring the hypotheses that considerable uronic carbon occurs in the soil and that this uronic carbon is a product of soil microorganisms, the belief that a considerable part of soil organic matter is microbially derived gains favor. This promptly focuses attention on the necessity for investigating the chemistry of microbial tissues and products in order more fully to advance our knowledge of the chemical nature and properties of soil organic matter.

## SUMMARY

The decarboxylation rate of uronic units contained in known constituents, soil organic matter, plant materials, and bacterial gums was investigated. The rate of $CO_2$-evolution of soil organic matter treated with boiling 12 per cent hydrochloric acid solution was greatest the first 15 minutes after the temperature had reached 135° C. After this initial peak, the rate fell abruptly and decreased gradually throughout the digestion period. The decarboxylation rate of the surface and subsoil uronides differed only in that the latter exhibited a more intense rate of decarboxylation when boiling began than did the former. About 9 to 23 per cent of the organic carbon of surface soils appeared to be uronic, whereas 19 to 30 per cent subsoil carbon was considered to be uronic The polygalacturonide from pure lemon pectin and the glucuronic acid from mesquite gum decarboxylated a little more slowly during the early stages of boiling than did soil organic matter, although the general shape of the rate curves was not greatly dissimilar. The rate of decarboxylation of uronic units of either natural or pectin-extracted plant materials was quite like that of plant gums. The proportion of uronic carbon to organic carbon of natural plant materials was much less than that of soil organic matter. The greatest loss of uronic units from the

various plant materials as a result of microbial decomposition took place the first 5 days. The rate of loss decreased as time progressed. At least half of the plant residues were higher in uronic content after 6 months of decomposition than at the end of 10 and 30 days, despite considerable loss of the total sample. The loss in weight of total sample after the first few days was proportionately greater than the loss of uronic units. This permitted an actual accumulation of uronic carbon as decomposition progressed. The decarboxylation rate of uronic units of bacterial gums and soil organic matter was very similar.

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# PHOSPHORUS-ADSORBING CAPACITIES OF SOME NEW JERSEY SOILS[1]

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Soils vary greatly in their ability to adsorb soluble phosphate ions (1). It is known that a soil's pH value, its content of clay, the chemical and mineralogical composition of this clay, and the nature and amount of each of the several cations that may be present in its exchange complex influence the quantity of phosphate ions adsorbed (4, 5, 6).

During the last several years, investigations concerned with the boron, potassium, magnesium, and lime needs of some important New Jersey soils have been completed and the results have been published (2, 3, 7, 8). It is the purpose of this contribution to present and discuss data concerned with phosphorus relationships in these same soils, with particular reference to their phosphorus-adsorbing capacities.

## EXPERIMENTAL METHODS

The soils were collected on the profile basis. All were virgin soils, except for three that were taken from areas which, at one time, had been under cultivation. The series names of the soils are somewhat at variance with those listed in previous studies because of a resurvey and reclassification of the soils of this state. Table 1 presents the old and new classifications, as well as the kind and method of deposition of the parent material of the soils studied.[2]

Cation-exchange capacity values were obtained by the BaAc method. Exchangeable bases were displaced with neutral normal $NH_4Ac$, and the amounts of Ca, Mg, and K in the extract were determined by the usual methods.

As it was necessary to bring all of these soils to a standard state if comparable data were to be obtained in the study of the influence of soil composition on P adsorption, the hydrogen state was decided upon. The H-soils were prepared by leaching portions of the original samples with 0.05 $N$ HCl until they were free of Ca, and then washing them with distilled water until they were free of chlorides.

Portions of the samples of the H-soils were then limed with CaO to pH 6.5 so that a study could be made of the influence of exchangeable Ca on P adsorption. The quantity of CaO necessary to do this was determined by the method of Lewis and Hardy (2).

The pH measurements were obtained on 1:2 soil to water suspensions by the use of a glass electrode potentiometer system.

The method developed and used for determining the P-adsorbing capacities of these soils was arbitrary, but the following fundamental principles that have been established as determining the extent of P adsorption by soils were kept in mind in formulating the procedure:

1. The pH value and exchangeable Ca content of a soil largely govern its adsorption of phosphate ions. At pH values greater than 6.0, the reaction between exchangeable Ca and phosphate ions, leading to the formation of insoluble calcium phosphates, is primarily responsible for the adsorption (5). At pH values below 6.0, adsorption is principally due to reactions with the ions and free oxides of Fe and Al (4, 5, 9) and to anion-exchange reactions (5, 6).

TABLE 1

*Soil types according to revised classification with information on parent materials*

| REVISED CLASSIFICATION | FORMERLY | PARENT MATERIALS | |
|---|---|---|---|
| | | Kind | How Deposited |
| *Coastal Plain Province* | | | |
| Sassafras loam | Sassafras | Sand-gravel | Residual soils deposited |
| Lakewood sand | Lakewood | Gray sand | in place from underlying |
| Evesboro loamy sand | Sassafras | Brown sand | Coastal Plain material |
| Colts Neck sandy loam | Colts Neck | Sands with me- | |
| Collington loam | Collington | dium glaucon- | |
| | | ite | |
| *Appalachian Province* | | | |
| Norton silt loam | Penn | Red shale | Glacial till |
| Lawrenceville silt loam | Lansdale | Silts | Jerseyan outwash |
| Chicopee silt loam | Merrimac | Gneiss-shale | Glacial outwash |
| Whippany silty clay loam | Whippany | Clays | Lacustrine |
| Bermudian silt loam | Bermudian | Red shale | Flood plain |
| Annandale loam | Washington | Gneiss-granite | Glacial till |
| Rockaway stony loam | Gloucester | Gneiss-schist | Glacial till |
| Squires loam | Dover | Limestone | Glacial till |
| Dutchess shale loam | Dutchess | Slate-shale | Glacial till |
| Palmyra gravelly loam | Fox | Limestone | Glacial outwash |
| Copake stony loam | Hoosic | Shale-limestone | Glacial outwash |
| Hoosic stony loam | Papakating | Gray shale | Glacial outwash |

2. The rate of adsorption of P is rapid, between 85 and 95 per cent of the soluble phosphate ions being adsorbed in the first few minutes of contact with soil (5).

Preliminary studies with 25-gm. samples of soil and a 1:6 soil-to-solution ratio showed that maximum adsorption of phosphate ions occurred at a concentration range between 50 and 75 m.e. P, whether supplied as diammonium or monocalcium phosphate. The adsorption process was essentially complete in 5 days.

Attempts to obtain adsorption data on these soils by the method of determining P difference in the solution before and after it had been in contact with the soil were not successful. The procedure finally adopted to obtain adsorption

indexes was that of analyzing the soil before and after it had been exposed to the phosphate solution. The unadsorbed phosphate ions were removed by washing with distilled water prior to the analysis of the soil for P.

The method in detail was as follows: Four 25-gm. samples of soil were weighed into as many 200-ml. widemouthed Erlenmeyer flasks. Two of these were treated with 150-ml. portions of a solution containing 50 m.e. P and two with the same amount of a solution containing twice that quantity of P. The samples were shaken intermittently by hand for 3 days and finally were allowed to stand for 1 week at room temperature. At the end of this period, the soil and solution were shaken, transferred to a filter paper in a Büchner funnel, filtered by the use of gentle suction, and washed with successive 50-ml. portions of distilled water until two successive leachates yielded only very small and rather uniform quantities of phosphate ions. The soil was then removed from the filter, air-dried, and analyzed for total P. The difference between the P content of the untreated and the phosphated samples of a soil represented its adsorbing capacity. Maximum adsorption was usually obtained with soil samples suspended in the solution that contained 50 m.e. P, but some soils had a slightly higher adsorption value in the more concentrated solution. The data obtained for all the soils are relative only, but they have value for comparative purposes.

### SOME PHYSICOCHEMICAL DATA ON THE SOILS TESTED

It was essential that pH values of the samples from the several profiles be determined prior to obtaining indexes of P adsorption, since these values governed the type of salt used in the adsorption tests. If the pH value of the soil sample was 6.0 or greater, an $(NH_4)_2HPO_4$ solution was used. If it was lower than 6.0, a $Ca(H_2PO_4)_2$ solution was substituted. A knowledge of the nature and content of exchangeable bases also aided in the interpretation of data obtained on the original samples.

Table 2 presents data on pH values, cation-exchange capacities, and exchangeable base contents of the soils tested. To simplify the discussions that follow, if more than one subhorizon was present in eluviation or illuviation zones, their properties were averaged and are listed under the A or B horizon in all the tables that follow.

Of the 17 soils tested, 5 were members of the Coastal Plain and 12 of the Appalachian Province. Their properties varied widely. For example, the pH values of the A horizons ranged from 4.3 for the Colts Neck to 7.4 for the Palmyra soil. The cation-exchange capacities of the A horizons ranged from 1.8 m.e. per 100 gm. for the Lakewood to 19.8 m.e. for the Norton soil.

The exchangeable Ca and Mg in the original samples varied widely. The minimum content of exchange Ca in the A horizon of these soils was 0.01 m.e. per 100 gm. in the Evesboro, and the maximum was 8.05 m.e. in the Copake. The exchange Mg values varied from 0.00 m.e. in the Evesboro to 3.35 m.e. per 100 gm. in the Bermudian.

Soils that originated either from limestone or shale-limestone material, such as the Squires, Palmyra, and Copake, were neutral or slightly alkaline in reac-

## TABLE 2

pH Values, cation exchange capacities, and exchangeable-base contents of soils by horizons

| SOIL SERIES | pH OF FIELD SOIL | | | pH OF HYDROGEN SOIL* | | | CATION-EXCHANGE CAPACITY† | | | EXCHANGEABLE BASES† | | | | | | | | | PROFILE DEPTH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Ca | | | Mg | | | K | | | |
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | in. |
| Sassafras | 4.4 | 4.4 | 4.7 | 3.55 | 3.70 | 3.95 | 7.7 | 7.1 | 2.3 | 0.38 | 0.40 | 0.28 | 0.31 | 0.40 | 0.50 | 0.20 | 0.09 | 0.02 | 41 |
| Lakewood | 4.4 | 4.7 | 4.7 | 3.70 | 3.80 | 3.95 | 1.8 | 1.4 | 0.8 | 0.05 | 0.03 | 0.03 | 0.05 | 0.04 | 0.03 | 0.01 | 0.00 | 0.00 | 33 |
| Evesboro | 4.4 | 4.3 | 4.9 | 4.20 | 4.20 | 4.70 | 2.6 | 3.1 | 1.6 | 0.01 | 0.03 | 0.16 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.00 | 46 |
| Colts Neck | 4.3 | 4.7 | 5.0 | 3.50 | 4.00 | 3.10 | 7.7 | 8.4 | 8.6 | 0.11 | 0.03 | 0.01 | 0.21 | 1.74 | 1.70 | 0.11 | 0.14 | 0.22 | 36 |
| Collington | 4.7 | 4.7 | 4.5 | 3.15 | 3.15 | 2.80 | 12.8 | 11.0 | 11.9 | 3.78 | 3.16 | 2.19 | 1.09 | 1.01 | 0.82 | 0.35 | 0.16 | 0.14 | 35 |
| Norton | 4.5 | 4.5 | 4.3 | 3.85 | 3.55 | 3.55 | 19.8 | 11.5 | 10.2 | 0.36 | 0.27 | 0.12 | 1.58 | 1.55 | 1.77 | 0.41 | 0.29 | 0.20 | 29 |
| Lawrenceville | 4.6 | 4.3 | 3.4 | 3.95 | 3.65 | 3.45 | 13.0 | 6.6 | 8.3 | 3.28 | 0.62 | 1.10 | 1.49 | 0.66 | 1.67 | 0.36 | 0.04 | 0.05 | 42 |
| Chicopee | 4.4 | 4.5 | 5.0 | 3.40 | 3.65 | 3.75 | 10.2 | 4.4 | 4.8 | 0.10 | 0.10 | 1.09 | 0.02 | 0.01 | 0.07 | 0.13 | 0.66 | 0.00 | 29 |
| Whippany | 5.9 | 7.3 | 7.9 | 3.70 | 3.65 | 3.95 | 9.4 | 16.9 | 15.5 | 3.22 | 5.27 | 6.65 | 3.00 | 7.85 | 7.26 | 0.15 | 0.19 | 0.16 | 32 |
| Bermudian | 6.1 | 5.0 | 5.0 | 3.70 | 3.70 | 3.70 | 13.2 | 12.6 | 10.6 | 6.44 | 4.00 | 2.11 | 3.35 | 2.30 | 2.33 | 0.18 | 0.03 | 0.01 | 27 |
| Annandale | 4.6 | 4.8 | 4.9 | 3.55 | 3.85 | 3.85 | 11.3 | 8.5 | 12.0 | 1.58 | 1.42 | 2.68 | 1.85 | 1.85 | 3.44 | 0.17 | 0.11 | 0.14 | 31 |
| Rockaway | 5.4 | 6.1 | 5.9 | 3.65 | 4.20 | 4.00 | 11.9 | 5.0 | 5.6 | 1.68 | 0.83 | 0.87 | 0.55 | 0.54 | 1.42 | 0.12 | 0.00 | 0.00 | 32 |
| Squires | 7.0‡ | 7.4‡ | 8.1‡ | 3.65 | 4.15 | .... | 7.0 | 7.5 | 8.1 | 7.40 | 3.30 | 3.83 | 2.35 | 2.15 | 3.59 | 0.11 | 0.03 | 0.00 | 31 |
| Dutchess | 7.0 | 5.7 | 5.8 | 3.75 | 4.00 | 4.15 | 12.7 | 5.8 | 4.5 | 7.35 | 2.80 | 2.50 | 3.05 | 1.50 | 1.90 | 0.45 | 0.00 | 0.00 | 24 |
| Palmyra | 7.4‡ | 7.3‡ | 7.3‡ | 4.30 | 4.00 | 3.85 | 6.3 | 4.4 | 5.8 | 3.46 | 2.65 | 2.92 | 2.65 | 1.46 | 2.15 | 0.18 | 0.00 | 0.00 | 28 |
| Copake | 6.9 | 6.7 | 7.0 | 3.45 | 3.95 | 4.20 | 11.4 | 5.9 | 4.9 | 8.05 | 3.91 | 2.76 | 1.00 | 0.60 | 0.60 | 0.14 | 0.00 | 0.00 | 19 |
| Hoosic | 5.5 | 5.2 | 5.0 | 3.60 | 4.40 | 4.05 | 9.0 | 6.1 | 5.4 | 3.97 | 1.81 | 0.93 | 0.65 | 0.97 | 0.82 | 0.33 | 0.07 | 0.02 | 21 |

* Prepared by washing samples with 0.05 N HCl and water until free of bases and chlorides.

† m.e. per 100 gms. soil.

‡ Free $CaCO_2$ and $MgCO_2$ present.

tion and contained moderate to large amounts of exchangeable Ca and Mg. Well-drained soils formed from acidic parent material, such as the Colts Neck, Norton, and Chicopee, were generally acid throughout their profiles and contained only small or moderate amounts of exchangeable Ca and Mg.

Previous studies (9) indicated that a relationship exists between the cation-exchange capacity and the ultimate pH value of a soil. The data in table 2 offered an opportunity to check this point. The results were negative. The absence of any relationship is, no doubt, explained by the alterations produced by the 0.05 $N$ HCl treatment of the soils[3] and by differences in the nature of their secondary clay minerals and in their content of organic matter.

TABLE 3

*Total P content of soils*

| SERIES | HORIZONS | | |
| --- | --- | --- | --- |
|  | A | B | C |
|  | *per cent* | *per cent* | *per cent* |
| Sassafras | 0.043 | 0.017 | 0.009 |
| Lakewood | 0.004 | 0.004 | 0.001 |
| Evesboro | 0.018 | 0.019 | 0.004 |
| Colts Neck | 0.056 | 0.077 | 0.102 |
| Collington | 0.073 | 0.062 | 0.055 |
| Norton | 0.028 | 0.010 | 0.002 |
| Lawrenceville | 0.047 | 0.022 | 0.026 |
| Chicopee | 0.047 | 0.033 | 0.033 |
| Whippany | 0.019 | 0.033 | 0.047 |
| Bermudian* | 0.054 | 0.047 | 0.041 |
| Annandale | 0.015 | 0.009 | 0.012 |
| Rockaway | 0.079 | 0.030 | 0.021 |
| Squires | 0.049 | 0.045 | 0.027 |
| Dutchess* | 0.073 | 0.034 | 0.033 |
| Palmyra | 0.066 | 0.041 | 0.032 |
| Copake* | 0.063 | 0.063 | 0.056 |
| Hoosic | 0.047 | 0.037 | 0.046 |

\* Samples chosen from areas that had once been under cultivation.

## TOTAL PHOSPHORUS CONTENTS OF SOILS

Table 3 presents data on the total P contents of the A, B, and C horizons of the 17 soils tested. The average P content of the A horizon of the Coastal Plain and Appalachian Province soils was 0.043 per cent. The P range in the Coastal Plain soils was between 0.004 per cent in the Lakewood and 0.073 per cent in the Collington. Similarly, in the Appalachian Province soils, the range was between 0.015 per cent in the Annandale and 0.079 per cent in the Rockaway. In 15 out of the 17 soils tested, the P contents of the B and C horizons were lower than those of the A horizons. The exceptions were the Colts Neck and

[3] Toth, S. J. The properties of soil ampholytoids prepared by different methods. Unpublished data.

Whippany soils; in which the P contents of the B and C horizons were greater than those of the A horizons.

The Sassafras, Colts Neck, Collington, Norton, Whippany, and Annandale soils were examined on the profile basis as to their contents of 0.05 $N$ HCl-soluble and electrodialyzable P. The purpose of the test was two-fold: first, to establish whether or not the contents of acid-soluble and electrodialyzable P were related in any manner to the total P, and second, to obtain any indica-

TABLE 4

*Total, 0.05 N HCl-soluble and electrodialyzable P in six soils*

| SERIES | HORIZON | FORM OF PHOSPHORUS | | |
|---|---|---|---|---|
| | | Total | Soluble | Electrodialyzable |
| | | *m.e.** | *m.e.** | *m.e.** |
| Sassafras | A | 3.521 | 1.056 | 0.120 |
| | B | 1.406 | 0.105 | 0.002 |
| | C | 0.739 | 0.070 | 0.000 |
| Colts Neck | A | 4.542 | 0.176 | 0.015 |
| | B | 6.232 | 0.186 | 0.008 |
| | C | 8.274 | 0.352 | 0.007 |
| Collington | A | 5.880 | 0.421 | 0.109 |
| | B | 5.000 | 0.105 | 0.006 |
| | C | 4.436 | 0.070 | 0.000 |
| Norton | A | 2.253 | 0.140 | 0.060 |
| | B | 0.880 | 0.110 | 0.014 |
| | C | 0.176 | 0.000 | 0.000 |
| Whippany | A | 1.584 | 0.210 | 0.020 |
| | B | 2.676 | 0.225 | 0.017 |
| | C | 3.802 | 0.700 | 0.340 |
| Annandale | A | 1.232 | 0.140 | 0.013 |
| | B | 0.774 | 0.070 | 0.003 |
| | C | 1.021 | 0.035 | 0.000 |

* Per 100 gm. soil in terms of pentavalent P.

tions as to the relative powers of the various soils for supplying available P. It was hoped to attain the latter point by comparing the contents of electro-dialyzable P in the surface horizons of the soils. The results of the test are presented in table 4.

In four of the six soils tested, the acid-soluble P decreased with depth in the profile. With the Colts Neck and Whippany soils, acid-soluble P increased with increasing depth. With each soil, however, the content of acid-soluble P varied in relation to the total P content. Differences existed between the soils, as indicated by the fact that the C horizon of the Colts Neck soil had a total P content of 8.274 m.e. per 100 gm. and an acid-soluble P content of only 0.352 m.e., whereas the same horizon of the Whippany soil, with a total P content of 3.802 m.e., had an acid-soluble P content of 0.700 m.e. Undoubtedly these variations are due to the difference in the type of P compounds in the two soils.

As was to be expected, the electrodialyzable P contents of all the soils were lower than the acid-soluble. The relative capacities of the soils to supply available P were in the following increasing order: Annandale, Colts Neck, Whippany, Norton, Collington, and Sassafras.

TABLE 5

*P-adsorbing cadcities of soils\**

| SERIES | FIELD SOIL† | | | HYDROGEN SOIL† | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Unlimed | | | Limed to pH 6.5 | | |
| | A | B | C | A | B | C | A | B | C |
| Sassafras | 18.2 | 16.9 | 5.4 | 10.0 | 14.9 | 4.4 | 4.9 | 7.1 | 2.9 |
| Lakewood | 0.03 | 0.76 | 0.22 | 0.03 | 0.50 | 0.16 | 0.01 | 0.22 | 0.09 |
| Evesboro | 10.1 | 12.0 | 5.6 | 7.2 | 9.5 | 5.6 | 4.3 | 4.5 | 2.8 |
| Colts Neck | 24.0 | 48.8 | 80.1 | 16.3 | 48.6 | 76.0 | 8.8 | 10.4 | 17.5 |
| Collington | 36.2 | 50.7 | 49.0 | 33.0 | 49.1 | 48.7 | 17.7 | 14.8 | 14.0 |
| Norton | 87.5 | 36.1 | 29.0 | 64.4 | 27.4 | 22.8 | 31.5 | 13.1 | 8.4 |
| Lawrenceville | 56.5 | 41.9 | 56.5 | 40.9 | 42.7 | 56.5 | 14.0 | 10.0 | 9.4 |
| Chicopee | 58.8 | 46.3 | 43.9 | 50.1 | 43.5 | 43.6 | 14.8 | 5.2 | 3.8 |
| Whippany | 55.8 | 134.1 | 116.5 | 50.6 | 106.9 | 95.7 | 5.2 | 6.4 | 5.9 |
| Bermudian | 15.3 | 41.3 | 40.7 | 38.1 | 39.7 | 40.2 | 7.2 | 9.6 | 8.6 |
| Annandale | 31.4 | 25.9 | 37.4 | 28.4 | 24.1 | 29.7 | 11.8 | 8.9 | 9.9 |
| Rockaway | 76.2 | 62.3 | 45.5 | 54.2 | 51.7 | 40.9 | 16.8 | 6.4 | 5.0 |
| Squires | 10.7 | 5.1 | 2.2 | 23.1 | 36.0 | ‡ | 4.7 | 3.8 | ‡ |
| Dutchess | 17.1 | 16.0 | 10.4 | 24.2 | 35.6 | 21.0 | 15.5 | 11.4 | 8.6 |
| Palmyra | 8.2 | 4.6 | 5.6 | 24.1 | 27.2 | 36.4 | 5.9 | 4.6 | 4.6 |
| Copake | 12.3 | 6.5 | 4.6 | 28.3 | 25.6 | 32.5 | 6.4 | 4.2 | 4.3 |
| Hoosic | 34.4 | 47.6 | 40.8 | 32.5 | 47.2 | 37.1 | 7.9 | 5.8 | 4.1 |

\* To obtain adsorbing capacity of soils in terms of tons of 20 per cent superphosphate per acre, multiply by the factor 1.42.

† In m.e. per 100 gm. soil, in terms of pentavalent P.

‡ Hydrogen samples could not be prepared because of presence of free carbonates of Ca and Mg.

## PHOSPHORUS-ADSORBING CAPACITIES OF SOILS

The P-adsorbing capacities of the A, B, and C horizons of the soils studied in the original, H, and H-limed-to-pH-6.5 states are presented in table 5.

The differences in the capacities are best noted by comparisons of the H soils, since, in this condition, the influence of exchangeable cations on P retention is obviated. The range in P-adsorbing capacities of the A horizons was between 0.03 and 64.4 m.e. per 100 gm. The ranges in the B and C horizons were 0.50 to 106.9 m.e. and 0.16 to 95.7 m.e. per 100 gm., respectively. The differences are probably due to variations in the clay content of the several soils, the composition and nature of their secondary clay minerals, and their content of free oxides of Fe and Al.

Following the introduction of calcium into the exchange complex, determinations of the P-adsorbing capacities of the limed soils always yielded values that

were lower than those of the H-soils. This is well illustrated by the data in table 5. The A horizons of the limed soils had an adsorption range between 0.01 m.e. and 31.5 m.e. P per 100 gm. The ranges for the B and C horizons were 0.22 to 14.8 m.e. and 0.09 to 17.5 m.e. per 100 gm., respectively. The lower adsorbing capacities of the limed soils were due to the fact that the exchangeable Ca was functioning primarily to adsorb soluble phosphate ions as insoluble calcium phosphates (1). As a consequence of this, the reported adsorption values are less than those obtained with the H-soils. It should also be noted that soils having high cation-exchange capacities generally adsorbed more P in the limed state than those possessing low cation-exchange capacities (tables 4 and 5).

The adsorbing capacity of the original samples, reported in table 5, is related to the field pH, content of exchangeable Ca, and cation-exchange capacity. It has been pointed out that the P-adsorbing capacity of limed soil is less than that of an H-soil, since in the former case P is retained principally as Ca-phosphate complexes, whereas in the latter case the retention is due to P adsorption by free oxides and anion-exchange reactions. It is logical to expect, therefore, that acid soils, which in their field states had a pH value of less than 6.0 and which were adsorbing P from monocalcium phosphate solutions, would adsorb more P than slightly acid or alkaline soils possessing pH values greater than 6.0 and suspended in diammonium phosphate solutions. The data in table 5 bear out this contention. The Collington soil, which has a pH value of 4.7, a low content of exchangeable Ca, and a high cation-exchange capacity value, adsorbed more P than the Dutchess soil with a pH value of 7.0, a high content of exchangeable Ca, and approximately the same cation-exchange capacity. Generally, however, it can be said that soils of high cation-exchange capacities adsorb more P than soils of low exchange capacities, whether in the field, H, or H-limed-to-pH-6.5 states.

The influence of texture on adsorbing capacity is indicated by the fact that the sand and loamy sand soils had lower adsorbing capacities than the loams or silt loams. For example, with the A horizons of the original samples, Lakewood sand adsorbed 0.03 m.e. P per 100 gm., Evesboro loamy sand, 10.1 m.e., and Sassafras loam 18.2 m.e.

The patterns of the adsorbing capacities of the soils are revealed by the data in table 5. These patterns are related in some degree to the stage of podzolization of the profiles. Soils of the Coastal Plain Province of New Jersey are generally podzolized to a greater degree than those of the Appalachian Province (2). Of the five Coastal Plain soils studied in the H state, four had greater adsorbing capacities in the B than in the A or C horizons. This is the result of the natural sequence of podzolic weathering, which leads to the accumulation of Fe and Al, as well as clay, in the B horizon. The exception to the rule is the Colts Neck soil, which exhibited the greatest adsorption in the C horizon. It is believed that evidences of podzolization in this soil, as yielded by adsorbing-capacity values, are offset by the increases in free iron oxides with depth. The Appalachian Province soils exhibit four definite patterns of adsorption in the A, B, and C horizons. These patterns are as follows:

1. No differences in adsorbing capacity.—This indicates that the profiles of the soils in this group are immature or poorly developed. Included in this group are the Bermudian and Annandale soils.

2. Adsorbing capacity decreases with depth.—The adsorbing capacity of the A horizon is greater than that of either the B or C horizon. The B and C horizons may have approximately the same adsorption value, or the C horizon may have a lower adsorbing capacity than the B. Soils of this group are generally weak in profile development and include the Norton, Chicopee, and Rockaway.

TABLE 6

*Silica and sequioxide content of 0.05 N HCl extracts of six soils*

| SERIES | HORIZONS | SiO₂ | Fe₂O₃ | Al₂O₃ |
|---|---|---|---|---|
| | | *m.e.** | *m.e.** | *m.e.** |
| | A | 2.23 | 7.76 | 0.35 |
| Sassafras | B | 5.51 | 9.33 | 0.41 |
| | C | 2.25 | 3.54 | 0.35 |
| | A | 0.52 | 0.09 | 3.66 |
| Colts Necks | B | 1.57 | 0.18 | 3.74 |
| | C | 2.40 | 0.27 | 5.12 |
| | A | 4.76 | 1.87 | 1.46 |
| Collington | B | 6.55 | 1.44 | 1.14 |
| | C | 7.50 | 3.00 | 1.12 |
| | A | 3.29 | 0.21 | 16.91 |
| Norton | B | 3.11 | 0.16 | 7.89 |
| | C | 4.48 | 0.20 | 8.19 |
| | A | 18.31 | 2.29 | 6.76 |
| Whippany | B | 40.98 | 4.23 | 16.60 |
| | C | 45.08 | 3.06 | 23.00 |
| | A | 2.41 | 0.17 | 9.11 |
| Annandale | B | 2.87 | 0.13 | 5.86 |
| | C | 3.24 | 0.19 | 3.97 |

\* Per 100 gm. soil.

3. Adsorbing capacity approximately the same in the A and B horizon with an increase or decrease in C.—Soils of this group exhibit only weak evidence of podzolization. They include the Rockaway, Lawrenceville, Palmyra, and Copake.

4. Adsorbing capacity increases in the B horizon and decreases in the C.—This pattern of adsorption would normally be ascribed to and be indicative of advanced podzolization. The Whippany, Hoosic, and Dutchess soils, which comprise this group, are only weakly podzolized, however, and the increase in adsorbing capacities in the B horizons is due to higher clay contents and not to the accumulation of Fe and Al, which in the normal podzol moved from the A to the B horizon. In this soil the prevailing pH is too high to allow such movement.

Soils that were originally acid generally had higher P-adsorbing capacities in the field than in the H state. Soils that were originally neutral or alkaline always had lower P-adsorbing capacities in this state than in the H state. When these H-soils were limed to pH 6.5, however, and the adsorbing capacities of the samples were compared to those of the original samples, the former were found to be smaller.

At first sight, the results seem to be contradictory. Consideration of the mode of preparation of the H-soils and of those that were limed to pH 6.5 yields the reasons for this behavior. In the preparation of H-soils, the original samples were leached with 0.05 $N$ HCl to remove the exchangeable bases. During this process considerable quantities of Fe and Al were lost from the samples because of their solubility in the acid. Since Fe and Al adsorb phosphate ions, the loss of these constituents from the sample reduced its P-adsorbing capacity. The losses of Fe and Al from the Sassafras, Colts Neck, Collington, Norton,

TABLE 7

*Relative P-adsorbing capacities\* of A-horizons of soils*

| SERIES | FIELD SOIL | HYDROGEN SOIL | |
|---|---|---|---|
| | | Unlimed | Limed to pH 6.5 |
| Lakewood | 1 | 1 | 1 |
| Evesboro | 2 | 2 | 2 · |
| Sassafras | 8 | 3 | 3 |
| Dutchess | 6 | 4 | 13 |
| Colts Neck | 9 | 5 | 10 |
| Squires | 4 | 6 | 4 |
| Copake | 5 | 7 | 5 |
| Palmyra | 3 | 9 | 8 |
| Annandale | 10 | 8 | 11 |
| Collington | 12 | 10 | 16 |
| Hoosic | 11 | 11 | 9 |
| Whippany | 18 | 12 | 6 |
| Bermudian | 7 | 13 | 7 |
| Lawrenceville | 14 | 14 | 12 |
| Chicopee | 15 | 15 | 14 |
| Rockaway | 16 | 16 | 15 |
| Norton | 17 | 17 | 17 |

\* The smaller the number, the less the adsorption.

Whippany, and Annandale soils are shown in table 6. The data in tables 5 and 6 do not show a direct relationship, however, between the quantities of Fe and Al lost because of solubility in 0.5 $N$ HCl and the loss in P-adsorbing powers of the soils. In some instances the loss of Fe and Al from a sample was high, whereas the loss in adsorbing power was comparatively small. Since the P-adsorbing power of a soil represents the net reaction between all the factors or reactions involved in adsorption, it does not necessarily follow that the reduction in adsorption should be correlated with the net loss of Fe and Al.

After the most important Coastal Plain and Appalachian Province soils of New Jersey had been tested by the standard procedure, they were arranged in the order of increasing P-adsorbing values of the A horizons in the field, H, and H-limed-to-pH-6.5 states, as indicated in table 7.

#### PHOSPHORUS-ADSORPTION AND CATION-EXCHANGE VALUES

It is known that P adsorption by soils and soil colloidal clays is accompanied by an increase in cation-exchange capacity (1, 9). The phosphated samples of

the Sassafras, Colts Neck, Norton, Chicopee, Annandale, and Dutchess soils were tested to determine the magnitude of the cation-exchange increases. The results of this examination are presented in table 8.

The largest increase in cation-exchange capacity (tables 5 and 8) was associated with the greatest P adsorption. Of six soils tested in the H state, the Norton, Colts Neck, Chicopee, Annandale, and Sassafras showed agreement with this generalization, especially in the surface horizons of the profiles. In these soils the increases in cation-exchange capacity were approximately equal to

TABLE 8

*Increases in cation-exchange capacity of six soils resulting from phosphate applications to maximum adsorption value*

| SERIES | HORIZON | FIELD SOIL | HYDROGEN SOIL | |
| | | | Unlimed | Limed to pH 6.5 |
|---|---|---|---|---|
| | | *m.e.** | *m.e.** | *m.e.** |
| Sassafras | A | 4.8 | 4.0 | 1.5 |
| | B | 7.7 | 7.0 | 3.7 |
| | C | 1.2 | 0.2 | 0.2 |
| Colts Neck | A | 5.8 | 5.4 | 0.6 |
| | B | 15.8 | 9.9 | 1.5 |
| | C | 27.6 | 17.1 | 8.5 |
| Norton | A | 24.2 | 21.8 | 14.5 |
| | B | 10.0 | 7.4 | 5.0 |
| | C | 12.1 | 10.7 | 3.5 |
| Chicopee | A | 18.6 | 15.0 | 4.0 |
| | B | 14.8 | 13.4 | 1.0 |
| | C | 14.5 | 12.5 | 1.8 |
| Annandale | A | 10.0 | 9.1 | 3.4 |
| | B | 9.3 | 8.7 | 3.7 |
| | C | 10.1 | 10.1 | 4.1 |
| Dutchess | A | 9.5 | 13.0 | 7.3 |
| | B | 9.3 | 16.3 | 9.2 |
| | C | 8.5 | 10.8 | 4.7 |

* Per 100 gm. soil.

one-third of the milliequivalents of $P_2O_5$ adsorbed. The Dutchess soil was the only exception. It is known that large increases in cation-exchange capacity are not always associated with P adsorption. This had previously been shown in studies of Colts Neck and Sassafras colloids (9).

The increases in exchange capacity in the several horizons of the six profiles studied do not follow any definite pattern. For example, with the Sassafras loam profile in the H state, the maximum increase was in the B horizon, whereas with the Norton silt loam profile it was in the A horizon. The cation-exchange increase as the result of P adsorption was always less with the samples that were limed to pH 6.5 than with the original or the H-samples (table 8).

### SOME CONCLUSIONS

The pattern of P adsorption within a soil profile is dependent upon a wide variety of factors, including texture, content of free $Fe_2O_3$ and $Al_2O_3$, nature

of the clay minerals, cation-exchange capacity, content and nature of the exchangeable bases, and pH value. Generalizations on the behavior of added phosphates cannot be based on pH values only, and this point is well illustrated by the data presented in this paper. Neither can they be based solely on the prevalent types of pedologic processes operating in an area. Each profile within an area has a more or less definite pattern of phosphate adsorption.

Since a pH value of 6.5 is normal to soils in a high state of fertility, the H soils that were limed to that value have been classified in groups of low, medium, and high P-adsorbing capacities of the surface horizons as shown in table 9.

TABLE 9

*Relative P-adsorbing capacities of 17 New Jersey soils**

| LOW | MEDIUM | HIGH |
|---|---|---|
| 1. Lakewood sand | 7. Bermudian silt loam | 13. Dutchess shale loam |
| 2. Evesboro loamy sand | 8. Palmyra gravelly loam | 14. Chicopee silt loam |
| 3. Sassafras loam | 9. Hoosic stony loam | 15. Rockaway stony loam |
| 4. Squires loam | 10. Colts Neck sandy loam | 16. Collington loam |
| 5. Copake stony loam | 11. Annandale loam | 17. Norton silt loam |
| 6. Whippany silty clay loam | 12. Lawrenceville silt loam | |

* The order is based on adsorption values of: low = 0–7 m.e. P per 100 gm. soil; medium = 8–12 m.e.; and high = 13–17 m.e. It refers only to the H-soils, after they had been limed to pH 6.5.

These P-adsorbing values suggest the relative rates at which phosphate should be applied to the several soils for best results under field conditions. This information has been utilized in pot and square tests of phosphates, the results of which are yet to be published.

## SUMMARY

The P contents and P-adsorbing capacities of soils of five Coastal Plain series and 12 Appalachian Province series of New Jersey were determined on the profile basis. The results show that:

The total P contents of the surface horizons of the Coastal Plain and Appalachian Province soils of New Jersey averaged 0.043 per cent. The P contents of the B horizons were slightly lower.

The P-adsorbing capacities of the surface horizons of these soils in a standard H state ranged from 0.03 m.e. P per 100 gm. for Lakewood sand to 64.4 m.e. for Norton silt loam.

Liming these H-soils to pH 6.5 resulted in marked reduction in P adsorption. For example, the P-adsorbing power of the A horizon of Norton silt loam was reduced by liming from 64.4 m.e. to 31.6 m.e. per 100 gm.

The P-adsorbing powers of the H-soils of a few profiles were lower than those of the original samples. This was due to the loss of Fe and Al by solution in the $0.05N$ HCl used to prepare them.

No one pattern of P adsorption was applicable to all the profiles tested. Adsorption was greatest in the A horizons of some and in the B horizons of others. In the remaining profiles a fairly uniform adsorbing capacity was noted in all three horizons.

Phosphate applications to the maximum adsorption value greatly increased the exchange capacities of soils in the field state.

Of six soils tested, maximum increases in exchange capacity were correlated with maximum adsorption in all but one soil, the Dutchess.

The A horizons of the soils of New Jersey, at pH values of 6.5, were classified into three groups of low, medium, and high P-adsorbing powers, respectively. Lakewood sand, Evesboro loamy sand, and Sassafras loam had the lowest P-adsorbing capacities, and Rockaway stony loam, Collington loam, and Norton silt loam the highest.

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# FACTORS INFLUENCING AVAILABILITY OF PLANT NUTRIENTS FROM SYNTHETIC ION-EXCHANGE MATERIALS

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In a previous paper, Arnon and Grossenbacher (3) reported results of an investigation on the suitability of synthetic ion-exchange materials known as Amberlites as carriers of adsorbed plant nutrients. Two principal combinations were investigated: (a) one in which all the nutrient ions, cations as well as anions, were furnished in an adsorbed form, and (b) another in which potassium and nitrogen were supplied by daily irrigations of a dilute $KNO_3$ solution but all the other nutrients were furnished as in (a). It was found that, whereas in the (a) treatment calcium and magnesium were unavailable for plant growth, good growth and fruiting were obtained in (b).

The cause of unavailability of calcium and magnesium was not apparent from the data then available. Grossenbacher (6) has even suggested that the unfavorable growth effects in the (a) treatment were to be explained not in terms of calcium and magnesium nutrition, but rather as due to an "unfavorable contact effect" occasioned by putting the "predominantly electronegative root surfaces" in touch with the "electropositive particles" represented in the nutrient medium by the anion-adsorbing Amberlite. The latter explanation was deemed inadequate by the present writers, for it failed to account for the concordant physiological evidence presented by Arnon and Grossenbacher (3): 1. markedly lower calcium and magnesium content of leaves and stems of tomato plants in the (a) treatment (3, table 7); 2. deficiency symptoms cured by addition of calcium and magnesium sulfate to the cultures; 3. the fact that recovery following addition of calcium and magnesium was accompanied by a marked increase in these elements in the vegetative tissues (3, table 8).

The "unfavorable contact effect" suggested by Grossenbacher (6) was based not only on a reinterpretation of the previously reported data (3), but also on certain new observations of variability in growth among his series of plants (6) receiving the same treatment in subirrigated culture pots. The nature of the Amberlite treatments involved in the new tests (6) was not specified. No such variability was observed with the Amberlite treatments (randomized and in triplicate) used by Arnon and Grossenbacher in the experiments previously reported (3, table 2).

The present investigation was undertaken to elucidate the chemical properties of a culture medium in which all the nutrient ions were supplied in an adsorbed form. The data obtained provide a basis for explaining the previously reported results of growth experiments with plants by Arnon and Grossenbacher (3) in the light of considerations similar to those which govern the availability of adsorbed ions from soil colloids (1, 4, 5, 7, 8, 9, 10, 11, 12). In addition, evidence

was obtained on reciprocal relations of adsorbed monovalent and divalent cations and anions in an artificial system, which bears on the interpretation of related phenomena in soils.

## EXPERIMENTAL PROCEDURES

Unless otherwise specified, the procedures and analytical methods used in the earlier investigation were followed. A modified benzidine method[1] for sulfate determination was used in obtaining the data presented in figure 3. Sodium was determined by the zinc uranyl acetate method, and chloride by silver nitrate titration.

### LEACHING OF MIXTURES OF AMBERLITES AND SAND

One-kilogram batches of the silica sand used for growing plants in the previously described subirrigated pot experiments (3, table 2) were washed with distilled water, dried, mixed with Amberlite-ions, placed in percolation columns, and leached 35 times with 1,000 cc. of one of three solutions respectively: distilled $H_2O$, $0.01M$ HCl, and $0.01M$ NaCl, the same 1,000 cc. volume of solution was used successively in the 35 leaching cycles. At the termination of the leaching cycles, samples of leachates were taken for analysis.

Two combinations of Amberlite-ions were mixed with the sand in the same proportions used previously (3). One included Ca, Mg, K, $NO_3$, $H_2PO_4$, and $SO_4$ (mixture 3) and corresponded to the "all Amberlite-nutrients" treatment from which calcium and magnesium were found unavailable for plant growth (3). The second combination included only four nutrients: Ca, Mg, $H_2PO_4$, and $SO_4$ (mixture 2), paralleling the previously used "all Amberlite except K and $NO_3$" treatment. The results of the analyses are given in table 1. Leachates of sand alone were used for comparison.

The analyses of the sand alone indicated that it contained appreciable amounts of calcium and sulfate, which appeared in the water leachate. Of interest is the higher calcium concentration in the NaCl leachate, suggesting a certain amount of exchangeable calcium. Except for an increased in leachable calcium and magnesium, the data show no marked effect of leaching with the acid.

A striking contrast, with respect to the concentration of divalent ions, was found between the leachates from the sand-Amberlite mixtures 2 and 3: the one containing four and the other six Amberlite ions. With the four Amberlite ions, appreciable amounts of the divalent cations calcium and magnesium and the divalent anion sulfate were found in the leachate. Phosphate behaved like sulfate. On the other hand, in the mixture of sand with the six Amberlite-ions, the concentration of the divalent ions in the leachates, cations as well as anions, was found to be exceedingly low. This was true whether water, HCl, or NaCl was used as the leaching agent. It is noteworthy that the amounts of Ca, Mg, and $SO_4$ recovered in the leachates from this sand-Amberlite mixture were lower than those leached by water from sand alone. Thus the addition of potassium-

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[1] P. R. Stout and E. Epstein. Unpublished.

Amberlite and nitrate-Amberlite not only has almost completely suppressed the leachability of the adsorbed calcium, magnesium, sulfate, and phosphate ions from a sand-Amberlite mixture, but has even removed from solution these ions, which were previously found in the water extract from sand alone (table 1).

Closely parallel data, not shown, were obtained from a companion leaching experiment in which a very pure Ottawa sand was used instead of the silica sand used for growing plants.

These results are in harmony with the previously reported physiological responses and chemical determinations (3) in which calcium and magnesium deficiencies were observed in the mixture of sand and six Amberlite-ions [designated "all Amberlite nutrients" in the preceding paper (3)].   What is new is the chem-

TABLE 1

*Results of chemical analyses of leachates*

| MIXTURE | LEACHING AGENT | pH | $Ca^{++}$ | $Mg^{++}$ | $K^+$ | $Na^+$ | $SO_4^-$ | $H_2PO_4^-$* | $NO_3^-$ | $Cl^-$ |
|---------|---------------|-----|------|------|------|------|------|------|------|------|
| | | | m.e. | m.e. | m.e. | m.e. | m.e. | m.e. | m.e. | m.e. |
| 1. Sand | $H_2O$ | 7.4 | 2.19 | 0.34 | 0.22 | 0.52 | 2.5 | <0.002 | <0.03 | 0.2 |
| | 0.01$M$ HCl | 2.3 | 4.86 | 0.66 | 0.30 | 0.50 | 3.2 | 0.1 | <0.03 | 10.7 |
| | 0.01$M$ NaCl | 7.1 | 3.32 | 0.34 | 0.22 | 9.35 | 3.4 | <0.002 | <0.03 | 11.0 |
| 2. Sand + 4 Amberlite ions (Ca, Mg, $H_2PO_4$, $SO_4$) | $H_2O$ | 4.9 | 1.80 | 1.72 | 0.19 | 0.45 | 3.9 | 1.2 | <0.03 | 0.2 |
| | 0.01$M$ HCl | 2.4 | 4.80 | 2.92 | 0.29 | 0.65 | 2.5 | 1.3 | <0.03 | 10.1 |
| | 0.01$M$ NaCl | 4.6 | 3.20 | 2.04 | 0.21 | 8.62 | 4.3 | 1.2 | <0.03 | 10.7 |
| 3. Sand + 6 Amberlite ions (Ca, Mg, K, $SO_4$, $H_2PO_4$, $NO_3$) | $H_2O$ | 4.3 | 0.18 | <0.004 | 5.33 | 0.13 | <0.01 | 0.1 | 6.7 | 0.2 |
| | 0.01$M$ HCl | 3.2 | 0.25 | <0.004 | 9.72 | 0.20 | <0.01 | 0.2 | 5.7 | 3.1 |
| | 0.01$M$ NaCl | 4.5 | 0.25 | <0.004 | 8.90 | 5.35 | <0.01 | 0.2 | 12.3 | 5.3 |

* Computed by the following formula: p.p.m. $\dfrac{PO_4}{95}$ · m.e. $H_2PO_4$ per liter.

ical finding that one more possible deficiency, that of sulfate, accompanied the lack of calcium and magnesium.   Since, in the growth experiments previously reported (3), sulfates of calcium and magnesium were used to correct the deficiency of the two cations, an additional supply of sulfate was automatically provided.

There remains to be explained the observed favorable effect on growth of adding NaCl to the "all-Amberlite nutrients" treatment (3).   The marked effect of leaching the six Amberlite-ions-sand mixture with NaCl was an increase of the nitrate and phosphate concentrations in the leachate.   It is difficult, however, to attribute the improvement in growth to an increased concentration of these otherwise adequately supplied nutrients.   It is more likely that the effects of NaCl are to be accounted for by exchange reactions with divalent ions originally present in the sand and also, to a limited extent, by exchange reactions with the divalent ions adsorbed on the Amberlites.   Small as these contributions of available nutrients would appear to be, from the data presented in table 1, their

importance in short-time experiments could be considerable if equilibrium conditions are envisaged: following absorption by the roots, successive quantities would be brought into solution. This conclusion is further strengthened by the observation that the large improvement in growth from the addition of NaCl was found only in the short-time pot experiments (3, table 2). In the large-scale tank experiments, calcium and magnesium deficiency was not prevented in the large plants, despite the presence of salt in the sand (3, table 5).

### RECIPROCAL EFFECTS OF ADSORBED MONOVALENT AND DIVALENT IONS

The suppressing effect of the added monovalent Amberlite ions on the leachability of the divalent ones (table 1) was investigated in greater detail by segregating the anions and cations into two separate groups to avoid possible mutual influences of Amberlite particles and ions of opposite charge.

The following working hypothesis was formulated: The negatively charged Amberlite (IR 100) carrying the adsorbed cations was envisaged as a colloidal surface which, in one instance, was fully saturated with the divalent cations calcium and magnesium (mixture 2, table 1) and, in another instance (mixture 3, table 1), was only partly saturated with these divalent ions, the balance of the negative charges being satisfied by the monovalent cation potassium. The divalent ions were readily displaced by water, HCl, and NaCl when they were present at saturation capacity on the negative Amberlite surfaces (mixture 2, table 1) but were scarcely exchanged when their degree of saturation was relatively low (mixture 3, table 1).

. Likewise, the positively charged Amberlite containing the adsorbed anions was regarded as, in one instance (mixture 2), being fully saturated and, in another (mixture 3), only partly saturated with divalent anions. Again, ionic exchange occurred at a high degree of saturation. At a low degree of saturation, the negatively and positively charged Amberlites were not only failing to release the adsorbed divalent ions, but were even capable of adsorbing and "fixing"the divalent ions derived from the sand itself. This would account for the disappearance of calcium, magnesium, and sulfate from the leachates in mixture 3 (table 1) after their presence was demonstrated in the water leachates of the sand without the Amberlites.

The hypothesis was tested experimentally for the cation and anion mixtures in the following manner: Starting with the proportions of cations used in the leaching experiment described above, several additional mixtures of Ottawa sand and cation-Amberlites were prepared which had the same K-Amberlite content but differed in the amounts of divalent cation-Amberlites; each successive mixture had twice the calcium- and magnesium-Amberlite content of the preceding one. In this manner, the degree of saturation of the divalent cations (calcium and magnesium are considered jointly, for the present purpose, as divalent cations) varied from 46.6 per cent in the initial mixture to 85 per cent in the 8 to 1 ratio of (Ca + Mg) to K. Each sand-Amberlite mixture was successively leached 35 times with HCl. The results are presented in figure 1.

The amounts of the divalent cations leached from the sand were sharply re-

duced following the addition of K-Amberlite, in accordance with the previous experiments. As the Ca- and Mg-Amberlite content was increased in successive mixtures, greater amounts of these ions were recovered in the leachates. When eight times the amount of Ca- and Mg-Amberlite furnished in the original mixture was added, the same amount of calcium and magnesium was recovered in the leachate as was found originally in the absence of K-Amberlite.

The leachability of potassium was only slightly reduced by increasing the proportions of calcium and magnesium in the series of mixtures. This is in accord with the theoretical and experimental data of Jenny and Ayres (8) for K-Ca-clay systems.

Similar findings are presented in figure 2 for the adsorbed anions. In this series, the degree of saturation of Amberlite surfaces with sulfate and phosphate
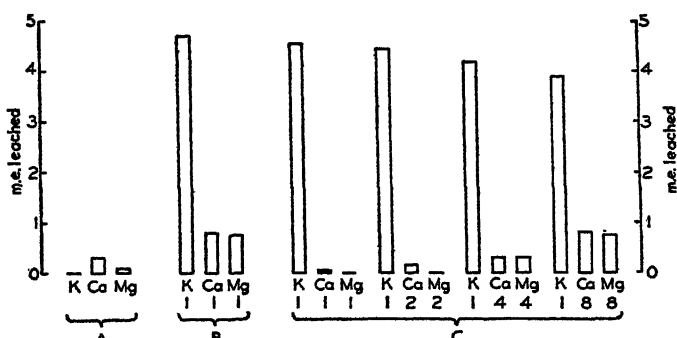


FIG. 1. RESULTS OF LEACHING OTTAWA SAND AND CATION-AMBERLITE MIXTURES
WITH 1,000 CC. OF 0.01$M$ HCl

A. Sand alone (500 gm.). B. (Sand + K-Amberlite) and (sand + Ca-Amberlite + Mg-Amberlite) leached separately. C. Sand + Amberlites of K, Ca, and Mg, mixed. 1 K = 11.3 m.e. adsorbed K. 1 Ca = 6.9 m.e. adsorbed Ca. 1 Mg = 3.0 m.e. adsorbed Mg. Multiples of these initial calcium and magnesium concentrations used as indicated.

was likewise varied by maintaining the Amberlite-nitrate constant and by adding to successive mixtures multiples of the original amounts of the other two Amberlite anions, sulfate and phosphate. As with the cations, the inclusion of Amberlite-nitrate sharply reduced the leachability of the adsorbed phosphate and sulfate. As the ratio of phosphate and sulfate to nitrate widened, greater amounts of these two ions were recovered in the leachate.

### COMPARISON OF AMBERLITE AND BENTONITE CLAY AS CATION ADSORBERS

The reduced leachability of divalent ions adsorbed on Amberlite in the presence of relatively large amounts of monovalent ions suggested the desirability of comparing the synthetic resin Amberlite with a natural clay of a type occurring in soils, such as bentonite. This was done for the cations calcium and potassium in the following manner:

Portions of suspended Otaylite hydrogen-bentonite #2 clay[2], with an exchange

[2] Obtained through the courtesy of I. Barshad, of the Division of Soils.

capacity of 1.2 m.e. per dry gram, were mixed with solutions of standardized KOH and Ca(OH)₂ by shaking for 5 days on a roller. The sum of the cations in the hydroxide solution was equal to the exchange capacity of the bentonite portion, but their relative proportions varied to give a series of K-Ca-bentonite preparations ranging from 0 per cent K and 100 per cent Ca to 100 per cent K
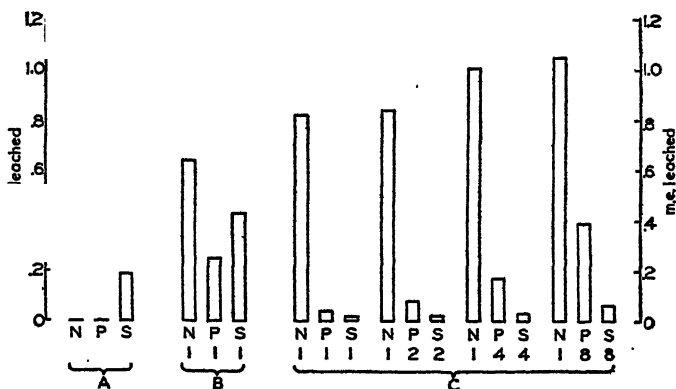


FIG. 2. RESULTS OF LEACHING OTTAWA SAND AND ANION-AMBERLITE MIXTURES·
WITH 1,000 CC. OF WATER

A. Sand alone (500 gm.). B. (Sand + Amberlite-NO₂) and (sand + Amberlite-SO₄ + Amberlite-PO₄) leached separately. C. Sand + Amberlites of nitrate, sulfate, and phosphate, mixed. 1 N = 16.7 m.e. adsorbed NO₃. 1 P = 0.823 m.e. adsorbed PO₄ (computed as H₂PO₄⁻). 1 S = 3.35 m.e. adsorbed SO₄. Multiples of these initial phosphate and sulfate concentrations used as indicated.
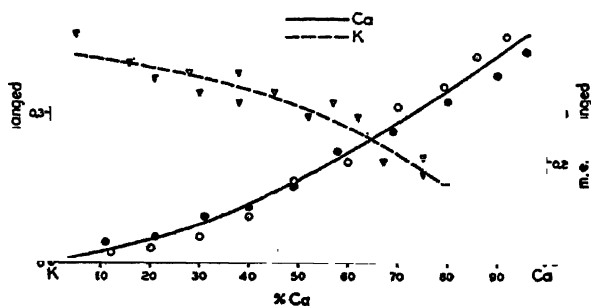


FIG. 3. EFFECT OF DEGREE OF SATURATION OF CALCIUM AND POTASSIUM ON THEIR
DISPLACEMENT BY HCl FROM CA-K-BENTONITE AND CA-K-AMBERLITE

Each point represents base exchange resulting from treating approximately 1 m.e. of adsorbed cations with 0.5 m.e. of HCl in 100 cc. of total volume. Amberlites: open circles and triangles.. Bentonites: solid circles and triangles.

and 0 per cent Ca. A series of comparable Amberlite preparations was also made in the same manner from hydrogen-Amberlite (IR 100 − H). After being shaken for 5 days, the bentonites were filtered through a Chamberland filter and the Amberlites through a folded filter paper. A corresponding portion of each original KOH and Ca(OH)₂ mixture was saved for analysis. The amounts of K + Ca adsorbed in either bentonite or Amberlite were determined by subtracting the

K and Ca recovered in the filtrates from the amounts initially present in the solution.

The bentonites and Amberlites, containing K and Ca in varying proportions, were then each suspended in a measured amount of HCl equivalent to *half* the total exchange capacity. The suspensions, total volume 100 cc. each, were mixed for 7 days on a roller. At the end of this period, the supernatant fluid was separated by filtration, in case of the Amberlites, and by decantation after settling, in case of bentonites. The supernatant fluids were analyzed for K and Ca to determine the extent of their relative exchange for H at the varying K and Ca ratios. The results are presented in figure 3.

The data indicate that the bentonite and Amberlite systems are similar, so far as the exchangeability of K and Ca is concerned, throughout the entire range of complementary-ion concentration. Thus, the interpretation of the data previously reported is to be sought not in terms peculiar to the synthetic resin Amberlite system used, but rather in terms of adsorbed-ion effects characteristic of well-known soil colloids. A further discussion of this point will be given in the succeeding section.

### DEGREE OF SATURATION AND AVAILABILITY OF PLANT NUTRIENTS

The previously reported physiological observations (3) and the chemical data now available on the properties of adsorbed ions bear affinity to a number of studies on the availability of plant nutrients from soil colloids as determined by degree of saturation on clay surfaces. Because of the electronegative charge of soil colloids, these studies were obviously concerned with nutrient cations. Of special relevance to our data are the concordant and converging lines of evidence that the availability to plants of adsorbed calcium is related to degree of saturation on soil colloids.

The special importance of exchangeable calcium in soils was stressed by Gedroiz (5). Several other investigators working with soils and plant systems found that the exchangeable calcium is available for plant growth only as its degree of saturation is relatively high. Jenny and Cowan (7) found that the growth of soybean plants in Ca-H-clay suspensions was sharply reduced when the degree of calcium saturation fell below 30 per cent of the total exchange capacity. Considerable attention has been given to sodium-calcium systems. Thus, Ratner (11) found that oats and wheat failed to grow in pot tests in a sodium-calcium system unless the degree of calcium saturation was in excess of 30–40 per cent. He attributed this failure of growth to the unavailability of calcium. A more comprehensive elaboration of this point of view is afforded by the data of Thorne (12), which include analyses of plants grown in sodium-calcium and potassium-calcium clay systems. The calcium content of tomato plants decreased as the proportion of either monovalent complementary ion, potassium or sodium, increased. Below 50 per cent of calcium saturation, growth was markedly reduced. In our own experiments the percentage saturation of the divalent bases, in the sand mixture associated with poor plant growth (3), was 46.6. Bower and Turk (4) recently found that naturally occurring alkali soils high in ex-

changeable sodium may not furnish an adequate supply of calcium to plants despite the presence of $CaCO_3$. This is in harmony with the finding of Gedroiz (5) that soils saturated with $NH_4$, Na, or K failed to support plant growth even when $CaCO_3$ was added to the cultures.

Allaway (1) investigated the availability to plants of calcium from different soil colloids as influenced by degree of saturation. Although the order varied for each colloid, yet in every case calcium availability increased with an increase in percentage of saturation. These findings are in essential agreement with those of Mehlich and Colwell (9, 10).

In the light of the experimentally demonstrated importance to plant nutrition of the degree of calcium saturation on soil colloids, it is significant that in most soils the total exchangeable bases consist chiefly of Ca and Mg. Hoagland and Martin[3], in an analysis of a number of fertile California soils, found that calcium and magnesium represented about 90 per cent of the total exchangeable bases. It seems legitimate, therefore, to envisage a physiological calcium deficiency as a factor contributing to the toxicity of alkaline and acid soils in which the percentage saturation of adsorbed calcium is reduced by a corresponding increase in sodium and hydrogen ions, respectively. The reduced calcium availability in acid soils may be especially distressing to plants, since, as found by Arnon and Johnson (2) in nutrient solutions, a high supply of calcium is important at acid reactions.

This investigation of Amberlites has led to observations on the reciprocal effects of ions of the same charge but different valence on the availability of adsorbed anion and cation nutrients for plant growth. The parallelism with soil colloids suggests a possible application of the synthetic resins as tools for investigating problems of ionic exchange in relation to plant growth.

## SUMMARY

To elucidate the causes of observed deleterious growth responses, an investigation was made of the chemical properties of a culture medium in which plant nutrients were supplied as adsorbed cations and anions on synthetic resins known as Amberlites.

In leaching experiments with sand mixtures, using $H_2O$, NaCl, or HCl as the leaching agent, it was found that the inclusion of adsorbed potassium markedly decreased the leachability of calcium and magnesium, and the inclusion of adsorbed nitrate-Amberlite decreased the leachability of sulfate and phosphate.

Availability, as measured by concentration in the leachate of adsorbed calcium and magnesium or sulfate and phosphate, was increased with an increase in the relative proportions of these ions to adsorbed potassium and nitrate, respectively.

The release of absorbed potassium and calcium by HCl from bentonite and Amberlite was found to be similar in a series of preparations having varying ratios of adsorbed K and Ca.

An interpretation is given of the adsorption reactions of Amberlites in terms of

[3] Unpublished.

degree of saturation of ions on adsorbing surfaces, and the relation of these findings to soils is discussed.

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# MECHANISMS OF RELEASE OF IONS FROM SOIL PARTICLES TO PLANT

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Ions cannot enter a plant unless they come into contact with the absorbing surfaces of the root. Even when contact is established, ions cannot enter the plant if the forces that hold them to solid particles of soil are greater than the forces represented by the tendency of the ions to be absorbed by the plant. We can thus consider that the plant and soil particles are competing for ions originating in the solid phase.

## TRANSFER OF IONS FROM THE SOIL SOLUTION

Our concept of the soil solution is that this medium *does not include ions held in the* electrical double layer at the surface of soil particles. Ions so held (by electrostatic forces) can doubtless be absorbed by plants (see below) but only as a result of interchanges with ions originating in the plant or on the root surfaces. The ions in the soil solution, however, are free to move therein and are not restrained from entering the plant by the attractive forces of the soil particle. This is best illustrated by the nitrate ion, which is not adsorbed by soil particles and, because of its high solubility, must always be taken by the plant *directly* from the soil solution.[2] The mechanism for this seems obvious. Inasmuch as concentration largely determines *the rate of entry* of ions into plants from culture solutions, it is evident that the process of acquisition of ions by plants *from the soil solution* is the result of bombardment of the root surfaces due to molecular (or ionic) movement of the ions contained in this medium.

Though this is equally true for all ions *in the soil solution, as defined herein*, it is obvious that ions capable of being adsorbed by the soil particles, for example, potassium and phosphate, are *largely* held in the adsorbed condition. Adsorbed ions and ions held in relatively insoluble compounds are in equilibrium with the soil solution. As the plant removes ions from the soil solution, the equilibrium is disturbed and more ions enter that medium and become susceptible to absorption by the mechanism described above.

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Although this manuscript presents no experimental evidence, it is based on the conclusions from experimental data produced and published from this laboratory over many years. My purpose is to arouse a more exact understanding of certain fundamentals concerning which there appears to be much confusion of thought in the current literature. I refer particularly to the widespread misunderstanding of what I mean by the "soil solution" and the effect of this misunderstanding upon the interpretation of the significance of contact exchange.

[2] It should always be kept in mind that the mere presence of nitrate ions in the soil solution requires an equal number of cations. These must be largely Ca, Mg, K, and Na at the pH values characteristic of soils.

It does not follow, however, that this latter class of ions is *entirely* absorbed by plants from the soil solution, and there is much experimental evidence that the root surfaces must come in contact with the soil particles to enable the plant to get *enough* of such ions to satisfy the requirement of the plant. Moreover, in many soils neither the concentration of ions in the soil solution nor the probable amounts brought into that medium as a result of absorption by plants appear adequate to account for the amounts of various elements actually taken up. A good example of this occurs in many soils in which the concentration of phosphate is frequently less than 1 p.p.m. of soil solution. In many such cases, the plants indicate no need for phosphate fertilizers, whereas culture solution experiments show that the concentration of this ion must be continuously maintained at 2 to 3 p.p.m. for most plants.

Since many soils are found to be productive without fertilization even when their soil solutions are relatively and absolutely low in one or another of the important ions, it seems clear that ions in the solid phase may in part enter the plant directly without entering the "liquid phase," as we understand that term. Much confusion on this point has resulted because many investigators do not recognize any difference between the soil solution and the interphase between the soil solution and the soil particle.

As has been pointed out, the solutions obtained by displacement, upon which most of our knowledge of the soil solution is based, do not include the ions held electrostatically by the soil particles.

Ions so held, however, are surrounded by a layer of oriented water molecules. If these ions are not removed, there must consequently be a layer of water molecules *between* the soil solution and the ionized soil surfaces.

If we accept the idea of an unhomogeneous interphase containing ions and water molecules between the soil particles and a homogeneous liquid phase, it is possible to give rational explanations of data obtained from displaced solutions and of the probable reactions in the interphase.

### TRANSFER OF IONS FROM THE SOLID PHASE

It appears from laboratory studies of suspensions of soil colloids and plant roots that cations initially held by the plant can be taken away by the colloid with a concurrent reverse movement. A theory by which this can be explained is predicated on the fact that the ions on a colloidal surface move back and forth in a limited zone known as the "oscillation volume."

If both the plant and the soil particle have layers of adsorbed cations (electrical double layers) and the two layers are merged by contact, the ions from the soil particle could exchange with those emanating from the plant. This seems obvious. It could not result, however, in the accumulation (net increase) of metallic cations by the plant, unless the cation supposedly emanating from the plant is $H^+$. The characteristic chemical complexes of plant root surfaces are largely carbohydrates (celluloses, hemicelluloses) and, though some such compounds have acidoid properties, these are so "weak" in the chemical sense, that it is

difficult to see why $H^+$ should leave them for clay particles, which appear, in general, to be stronger acids.

It thus appears much more likely that such transfers are brought about by acids which ionize *after* they enter the interphase, the source of such acids being small amounts of excreted organic acids and the large amounts of $CO_2$ from root respiration.

The only obstacle to the conclusion that $H^+$ from $CO_2+H_2O$ is the dominant factor in removing cations from the solid phase in all cases is that $CO_2$ does not give sufficiently high $H^+$ concentrations at *equilibrium* when the pH is that normally existing in the soil solution. This objection becomes trivial, however, if we clearly recognize that the interphase *does not* represent an equilibrium condition. Inasmuch as it is not an equilibrium, pH of the interphase cannot be measured, but the assumption that the condition at the interphase is equivalent to a system characterized by a low pH is justified by the low pH values observed when $CO_2$ is passed rapidly into water.

In conclusion, it appears that the usual explanation of "contact exchange" can account for a much more limited transference of ions than appears probable as the result of acid excretions and $CO_2$. The mechanism outlined above can also explain the release of anions (phosphate) to the plant by contact exchange. If the $H^+$ at the interphase is represented by *any pH lower than that of the soil solution*, the phosphate released by solution of calcium phosphate will be increased. Moreover, the anions of excreted organic acids could also displace adsorbed phosphate to the limited extent observed in our experiments with phosphated kaolinite.

In contact exchange, as we should prefer to explain it, the ions involved are detached from the soil particles and enter the zone of influence of the root surfaces so immediately in point of time or distance from the soil particles that they are not at any time a part of the homogeneous liquid phase which we call the "soil solution."

The soil solution is *in equilibrium* with the gaseous phase of the soil, air containing $CO_2$, and this in turn with the atmosphere, so that the normal escape of $CO_2$ from plant roots does not decrease the pH of the soil solution although it enhances the acidity of the interphase. This explains the anomaly that the major effects of contact can be assigned to acidity when the only measurable pH values are higher than those which could produce the effects observed.

# RAPID CHEMICAL SOIL AND PLANT TESTS

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Rapid soil and plant tests as aids in determining fertility requirements of plants have aroused considerable interest in recent years. Because of the relative speed with which these tests can be run, they have been employed practically on a wide scale.

Major emphasis has been placed on soil tests, but considerable attention has also been given to rapid tests for soluble nutrients in plants and some study given to rapid determination of total nutrients in plants. Soluble nutrients in soil have been used as an index of nutrients available for plant growth. Soluble nutrients within the plant have been used as an index of nutrients recently taken into the plant or reflecting recent metabolism. Total nutrients in the plant have been considered to picture the complete nutritional history of the plant.

More recently, attempts have been made to increase accuracy by improving the technique (5, 10, 11) or by better interpreting the results (1, 6, 7, 8, 9). Certain changes in reagents, procedure, and reading of tests by photometric means have permitted a closer calibration of results. Correlation with actual crop performance has aided in intelligent application of rapid test results and enhanced the utility of the test. As great as this progress has been, there is need for further improvements in technique in running the tests and intelligent interpretation of the tests.

A rapid reliable system of analysis for soluble nutrients in soils and plants and for total nutrients in plants would be an aid in interpretation studies. Such a system using similar reagents and standard curves for the three categories and varying only in preparation of the sample or aliquot chosen for analysis is here presented in detail. Application of these analyses in attempts to determine the fertility needs of spinach is also presented.

## METHODS OF ANALYSIS

### *Apparatus*

A photoelectric colorimeter with suitable filters. A Fisher electrophotometer with a 425 (blue), 525 (green), and 650 (red) filter has been satisfactorily used for all tests described in this paper.

Photometer tubes. Specimen vials 25 by 80 mm. may be used, provided some selection to exclude unusual tubes is made (10).

Waring blendor.

Funnel vials. Arthur H. Thomas Co., blueprint No. 2132-1.

Mill for grinding plant material. The Wiley Mill, intermediate model, is very satisfactory for this purpose.

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Wooden racks to hold 12 funnel vials. Wooden racks to hold 13 photometer tubes.

Erlenmeyer flasks, 250-ml. and 50-ml. marked at 50 ml.

Hot plate with uniformly heated surface and at least three controls to give temperatures of approximately 100°, 200°, and 300°C.

Drying oven.

Pipettes, serological, 5- and 10-ml. graduated at 0.1-ml. intervals; 1-ml. graduated at 0.01-ml. intervals.

Automatic burettes for dispensing solutions.

## Reagents and Solutions

All reagents are of c.p. grade unless otherwise indicated. Wherever possible, Baker's analyzed reagents were used.

### Extraction

Morgan's Universal extracting solution. Normal sodium acetate buffered at pH 4.8. It is most conveniently made up in a large bottle marked at 18 liters. Then, 1,800 gm. of sodium acetate and approximately 450 ml. of glacial acetic acid are dissolved in water and diluted to the proper level.

Carbon, activated Darco grade 0-97.

### Wet ashing

Sulfuric acid, concentrated, nitrogen-free.

Hydrogen peroxide, Superoxol, Merck.

### Determination of nitrogen

Modified Graves reagent. Mercuric chloride, 3.5 gm., and sodium chloride, 40 gm., are mixed and dissolved in about 750 ml. of water in a 2,000-ml. volumetric flask. The contents are diluted to mark, mixed, and stored in a brown bottle. The reagent will keep for at least several months.

Titanous chloride, 20 per cent solution, La Motte. Preferably purchased in 1-ounce bottles. If larger quantities are used or opened bottle is kept for some time, the solution must be protected from oxidation.

Sodium hydroxide, 15 per cent by weight.

Gum arabic, U.S.P., Arthur H. Thomas grade. A 0.25 per cent fresh solution in water.

Nitrogen standard. Ammonium chloride (0.0764 gm.) dissolved and diluted to 1 liter with extracting solution = 20 p.p.m. of nitrogen.

### Determination of phosphorus

Ammonium molybdate, 2.5 per cent in 6 $N$ $H_2SO_4$.

Amino-naphthol-sulfonic acid. Fifteen grams of sodium bisulfite, anhydrous, is dissolved in about 250 ml. of water and 0.5 gm. of pure, dry 1 amino-2 naphthol-4 sulfonic acid and 1.5 gm. of anhydrous sodium sulfite are added. The contents are shaken, made up to 500 ml., and stored in a brown bottle. The reagent will keep for several weeks.

Standard phosphorus. Monosodium phosphate, monohydrate (0.0890 gm.), dissolved and made up to 1 liter with extracting solution = 20 p.p.m. of phosphorus.

### Determination of potassium

Sodium cobaltinitrite. Cobaltous nitrate (6.25 gm.) and 75 gm. of sodium nitrite are dissolved in about 175 ml. of water in a 250-ml. volumetric flask. Then 5 ml. of 99.5 per cent acetic acid is added and mixed very gently at first to prevent loss by foaming. The solution is covered with a beaker and allowed to stand overnight to permit the escape of nitric oxide. It is then diluted to 250 ml., mixed well, filtered, and stored in a brown bottle kept in refrigerator.

Isopropyl alcohol, 99 per cent.

Formaldehyde.

Gum arabic, same as for nitrogen.

Standard potassium. Potassium chloride (0.0955 gm.) dissolved and diluted to 1 liter with extracting solution = 50 p.p.m. of potassium.

### Determination of calcium

Ammonium oxalate, fine crystals, ground to fine powder with mortar and pestle before use.

Gum arabic. Same as for nitrogen.

Standard calcium. Calcium acetate, dihydrate (0.4395 gm.), dissolved and diluted to 1 liter with extracting solution = 100 p.p.m. of calcium.

### Determination of magnesium

Titan yellow (Dr. Grubler quality preferred, although Eastman No. 4454 is satisfactory), 0.2 gm., in 400 ml. of 50 per cent methyl alcohol.

Sodium hydroxide. Same as for nitrogen.

Standard magnesium. Magnesium sulfate, tetrahydrate (0.0881 gm.), dissolved and diluted to 1 liter with extracting solution = 10 p.p.m. of magnesium.

## Procedures

### Preparation of sample

Soil. The sample upon being brought into the laboratory should be air-dried and sieved to remove debris. A rolling pin to break up clods is very useful. In storage, care should be taken to avoid the presence of fumes, such as ammonia and hydrochloric acid, and contamination from nonvolatile substances.

Plant. Care should be exercised to avoid any adhering soil particles. The larger samples must be cut in small pieces. For soluble nutrients, the fresh minced tissue is weighed for extraction, and a sample is taken at the same time for dry weight. This is dried at a temperature of 150–180°F. Where soluble and total nutrients are both being determined, this sample for dry weight can later be ground for total analysis. The sample is ground in a Wiley mill or other suitable apparatus to pass a 40-mesh screen. The ground dried material can also be used for determining soluble nutrients.

### Extraction

Soluble nutrients in soils. A 12.5-gm. sample of soil is placed in a 50-ml. Erlenmeyer flask. One-half teaspoonful of activated charcoal and 25 ml. of extracting solution are added. The flask is stoppered, and the contents are shaken for 1 minute and passed through a Whatman No. 1 filter paper into a funnel vial. The vial is stoppered until the tests are run. The filtrate will be referred to as "soil extract."

Soluble nutrients in plants. Five grams of fresh minced or 1 gm. of dried, finely ground tissue is placed in a Waring blendor and 1 teaspoonful of activated charcoal and 200 ml. of extracting solution are added. The contents are agitated for 5 minutes and passed through a Whatman No. 1 filter paper into a 250-ml.

Erlenmeyer flask. The flasks are stored in a refrigerator until used.[2] The filtrate will be referred to as "plant extract."

Total nutrients in plants. A 0.2-gm. portion of finely ground, well-mixed dry plant material is placed in a 50-ml. Erlenmeyer flask previously marked at 50 ml.[3] Then 3 ml. of concentrated sulfuric acid is added and the contents are well mixed and allowed to stand for 10 minutes. The flasks are gently heated on a hot plate or microburner until clouds of white fumes are given off. Heating is continued for at least 5 minutes. The flasks are removed and cooled, and 1 ml. of hydrogen peroxide is slowly added. A small funnel is placed in the neck of the flask, which is reheated to a boil and kept slowly boiling for several minutes. If the contents are not clear, the flask is again removed, cooled somewhat, and 0.5 ml. of hydrogen peroxide slowly added. The flask is reheated until the contents have again boiled for several minutes. The process of cooling, adding

TABLE 1

*Summarized data for preparation of standard curves*

| ELEMENT | USEFUL RANGE | STANDARD SOLUTION | DILUTED TO* | FILTER | NULL ADJUSTMENT |
|---|---|---|---|---|---|
| | *p.p.m.* | *p.p.m.* | *ml.* | | |
| Nitrogen | 0–20 | 20 | 10 | 425, blue | 100 |
| Phosphorus | 0–10 | 20 | 20 | 425, blue | 0 (log scale) |
| Potassium | 0–50 | 50 | 5 | 650, red | 100 |
| Calcium | 0–50 | 100 | 20 | 425, blue | 100 |
| Magnesium | 0–5 | 10 | 20 | 525, green | 90 |

* Diluted with extracting solution before adding reagents.

hydrogen peroxide, and boiling is repeated as often as is necessary to remove most of the color.

Once the contents are colorless, or nearly so, the funnel is removed and the flask is placed on low heat for several minutes to expel any excess hydrogen peroxide. The flasks are then cooled and extracting solution is added to bring the contents up to the mark. The flasks are stored for several days to effect the solution of any calcium which may have precipitated as a sulfate. The diluted contents will be referred to as the "ash extract."

*Standard curves and their use in estimating amounts of nutrients in soils and plants*

The amounts of nutrients present are determined by comparing photoelectric colorimeter readings of unknowns with those of standard curves prepared from standard solutions. Information for the preparation of standard curves is outlined in table 1. In determining the photoelectric colorimeter readings of nutrients present in soils or plants, similar null adjustments and filters are used as

[2] Many extracts will keep well without refrigeration.
[3] It is convenient to prepare 12 samples at one time. A blank using 0.2 gm. pure sucrose treated in the same way as the plant material is also prepared at this time. This will be referred to as the "ashing blank."

in the preparation of standard curves. For all standard curves and soluble nutrients in soils and plants, the photoelectric colorimeter is adjusted to desired null reading with a blank made up from extracting solution and carried through the entire procedure. In setting the electrophotometer for total nutrients in plants, use is made of a blank prepared from the solution of ashed sucrose (ashing blank). An aliquot of the ashing blank equal to that of the plant ash extract taken for determining the specific nutrient is diluted to volume with extracting solution and carried through the entire procedure. For example, in determining total calcium in plants, the electrophotometer would be adjusted to 100 with a blank prepared 15 minutes before from 2.5 ml. of ashing blank diluted to 20 ml. with extracting solution and treated with ammonium oxalate.

*Determination of nitrogen*

Soluble nitrogen in soil and plant extracts. A 10-ml. portion of plant extract, or 5 ml. soil extract plus 5 ml. extracting solution, is placed in a 50-ml. Erlenmeyer flask and 2.25 ml. of water, 2.5 ml. of sodium hydroxide, and 0.25 ml. of titanous chloride are added. The contents are mixed and allowed to stand for 10 minutes. They are then passed through a Whatman No. 1 filter paper into a funnel vial. Then 10 ml. of the filtrate is pipetted quickly into a photometer tube already containing 10 ml. of the modified Graves reagent mixed with 0.5 ml. of gum arabic solution. The contents are mixed with flat-bottomed glass rods and allowed to stand for 15 minutes before readings are taken with the photoelectric colorimeter.

Total nitrogen in plant material. To 1 ml. of ash extract pipetted into a photometer vial, 9 ml. of extracting solution, 2.5 ml. of water, and 2.5 ml. of sodium hydroxide are added. The contents are mixed and 10 ml. of the solution is pipetted into a photometer vial already containing 10 ml. of modified Graves reagent mixed with 0.5 ml. gum arabic. The contents are stirred, allowed to stand 15 minutes, and readings are taken with a photoelectric colorimeter.

*Determination of phosphorous*

A 5-ml. portion of soil or ash extract, or 10 ml. of plant extract, is diluted to 20 ml. with extracting solution. Then 4 ml. of ammonium molybdate is added, the contents are stirred with a glass rod, and 2 ml. of amino-naphthol-sulfonic acid is added. The contents are again stirred and allowed to stand for 15 minutes before readings are taken with the photoelectric colorimeter.

*Determination of potassium*

In a photometer vial is placed 2 ml. of soil, 1 ml. of plant, or 0.5 ml. of ash extract. The extract is diluted to 5 ml. with extracting solution, and 3 ml. of formaldehyde and 0.25 ml. of gum arabic are added. Then 2 ml. of sodium cobaltinitrite solution is added. The contents are mixed by rotating the tubes and allowed to stand for 5 minutes. From a 10-ml. automatic pipette at a constant height above the vial, 10 ml. of isopropyl alcohol is added directly to the liquid. The vial is immediately stoppered and inverted three times. It is then allowed to stand for 15 minutes before readings are taken with the photoelectric colorimeter.

*Determination of calcium*

In a photometer vial is placed 1 ml. of soil, 10 ml. of plant, or 2.5 ml. of ash extract. The contents are diluted to 20 ml. with extracting solution, and 0.25 ml. of gum arabic solution is added and mixed. Approximately 0.3 gm. of ground ammonium oxalate is added by a measuring spoon. The contents are stirred and allowed to stand for 15 minutes. Then they are again stirred, and readings are taken 1 minute later in the photoelectric colorimeter.

*Determination of magnesium*

One milliliter of soil, plant, or ash extract is pipetted into a photometer vial and diluted to 20 ml. with extracting solution. One milliliter of titan yellow solution is added and the contents are mixed. This is followed by addition of 3.5 ml. of 15 per cent sodium hydroxide. Again the contents are well mixed. Five minutes after the sodium hydroxide is added, the contents are again mixed and readings are taken in the photoelectric colorimeter.

*Discussion of methods*

The methods of analysis of soils and of soluble nutrients in plants are based on the use of Morgan's extracting solution (4). Greater accuracy in determining the elements has been achieved by making certain changes in reagents and procedure and by using a photoelectric colorimeter to measure the amounts of nutrients present. Use of charcoal, in making the extraction, to provide clear soil filtrates and the potassium reagent used follow the recommendations of Peech and English (5). The extraction of soluble plant nutrients follows the procedure of Hester (2).

The rapid ashing of plant material is based on the method proposed by Lindner (3).

Individual discussion of various tests follows:

Nitrogen. The amount and the sizes of particles of white precipitate formed are dependent on several factors. The order of mixing, the presence of protective colloid, and pH all have an important bearing. Using a dilute reagent well mixed with gum arabic, into which is pipetted the unknown, has given accurate, reproducible results. The amount of gum arabic added is sufficient to prevent precipitation of yellow or red oxides of mercury. If these compounds should appear, it is most likely that too much alkali has been added or the extracting solution was not properly buffered.

Since Graves reagent is capable of determining only ammonium nitrogen, the other forms of soluble nitrogen must first be reduced to the ammonium form. This is accomplished with soil and plant extracts by the use of titanous chloride. The procedure is very rapid and effective for nitrate nitrogen but not so effective for nitrite nitrogen. As nitrite nitrogen is present in comparatively small quantities in both extracts, the test does not lose its practical value.

In preparing the ash extract, nitrate nitrogen is reduced to the ammonium form in the presence of organic matter before hydrogen peroxide is added. The organic nitrogen is later reduced to the ammonium form as ammonium sulfate.

Continued heating with hydrogen peroxide after all organic matter is destroyed would oxidize some nitrogen with a corresponding loss.

The method is satisfactory for determining 0.5 to 20 p.p.m. of nitrogen in 10 ml. of the solution. Use of the recommended aliquots permits determination of 20 to 800 p.p.m. in fresh plant tissue, 4 to 160 pounds per 2,000,000 pounds of soil, and 0.12 to 5.0 per cent total nitrogen in dry plant material.

Phosphorus. Rapid mixing of the acid solution of ammonium molybdate with diluted extracts ensures elimination of interference with amounts of silica usually found. Interference of nitrate and ferric iron is overcome by means of sodium bisulfite. The blue color formed upon addition of the reducing agent increases in intensity for a number of hours unless heat is used. Reproducible results can be obtained in the cold, however, after 15 minutes.

The method is satisfactory for concentrations ranging from 0.2 to 10 p.p.m. of phosphorus in the diluted extract. With the aliquots recommended, this is satisfactory for 16 to 800 p.p.m. of phosphorus in the fresh plant tissue, 2 to 160 pounds per 2,000,000 pounds of soil, and 0.01 to 1.0 per cent in dry plant tissue.

Potassium. In determining potassium by rapid methods, it must be remembered that not only is the reaction subject to potassium concentration but it may be influenced by temperature, pH, ammonia present, order and rate of mixing reagents, and protective colloid used.

The sodium cobaltinitrite reagent suggested by Peech and English (5) is less subject to temperature variations than many other reagents of this type. If there is a large variation in the temperature, however, separate standard curves should be drawn for every 10° C.

The amount of potassium precipitated as the cobaltinitrite is also dependent upon the pH of the solution. The buffering effect of the extracting solution helps to maintain a constant pH and is satisfactory, provided large amounts of ash extract are not used. About 1 ml. of ash extract is the upper limit that can be used without obtaining variations in precipitate.

Ammonia can replace potassium in the cobaltinitrite precipitate formed. Its effect is greater when larger concentrations of potassium are present. Use of formaldehyde eliminates interference of ammonia in concentrations usually present.

The order and the rate of mixing reagents also affect the amount and size of individual particles formed during precipitation. It is a simple matter to keep the order of mixing reagents constant. The rate of adding isopropyl alcohol is controlled by using a 10-ml. automatic pipette at a constant height above the vial. Complete mixing is ensured by inverting the vials three times.

Gum arabic used as a protective colloid aids in the formation of uniform, small-sized particles of precipitate that remain in suspension for a long time.

The method is satisfactory for potassium in concentrations ranging from 1 to 50 p.p.m. For the aliquots recommended this is equivalent to 200 to 10,000 p.p.m. in fresh plant tissue, 10 to 500 pounds per 2,000,000 pounds of soil, and 0.25 to 12.5 per cent total potassium in dry plant tissue.

Calcium. The calcium determination is influenced by the size of particles of ammonium oxalate used, by pH of solution, and by protective colloid present.

Variations in calcium determinations due to use of different lots of ammonium oxalate were eliminated when the ammonium oxalate was first ground to a fine powder in a mortar before use. Considerable variation in the amount of ammonium oxalate used was of no consequence.

Again the pH of the solution is kept fairly constant by use of buffered solutions. Using aliquots of ash extract larger than 2.5 ml. lowers the pH to a point where it affects the solubility of calcium oxalate formed. Precipitation of calcium as the oxalate at pH approximately 4.8·reduces precipitation of other elements.

Unlike gravimetric procedures, it is necessary to have the calcium oxalate precipitate in small particles which will not settle out readily. The use of gum arabic is an aid from this standpoint. Stirring the contents of the tube about a minute before reading will again bring into suspension the small calcium oxalate particles that have settled out. The minute's time before reading enables the larger ammonium oxalate crystals to settle out.

The method is satisfactory for determining 2 to 50 p.p.m. of calcium in 20 ml. of solution. With the recommended aliquots this is equivalent to 160 to 4,000 p.p.m. in fresh tissue, 160 to 4,000 pounds per 2,000,000 pounds of soil, and 0.40 to 10.0 per cent total calcium in dry plant tissue.

Magnesium. There are various interfering substances in the titan yellow reaction. The presence of aluminum, manganese, calcium, and iron affects the colors produced. In addition, the pH also has some influence on color reaction.

In the method presented, small aliquots are used. The concentrations of interfering substances are therefore usually low and their effects are reduced to relative unimportance. Determination of very small quantities of magnesium is practical only with some mechanical means of measurement such as the photometer.

Determination of small quantities of magnesium can be accomplished without any protective colloid, provided too long standing is not allowed.

The pH is controlled by adding a constant amount of alkali to a buffered solution. Amounts of ash extract larger than 1 ml. should not be used because of the effect on pH.

The method is capable of determining 0.02 to 5 p.p.m. of magnesium in 20 ml. of solution. For recommended aliquots, this is equivalent to 16 to 4,000 p.p.m. in fresh plant tissue, 1.6 to 400 pounds per 2,000,000 pounds of soil, and 0.01 to 2.5 per cent of magnesium in dry plant tissue.

*Precision and Accuracy*

In general, tests can be repeated with a precision of at least ± 10 per cent. Precision is enhanced by use of clean, well-matched tubes, free of scratches. The procedure must be followed carefully.

Use of photometer readings about midway in the curve will give greatest accuracy in most cases. The determination of phosphorus is an exception because the standard curve is a straight line. With the other determinations, the curve tends to flatten at higher concentrations. This will give a small change in reading for a large change in concentration. Such readings should be avoided by use of smaller aliquots.

Accuracy in several cases is influenced by the presence of diverse ions. It is, therefore, important to take the smallest aliquot which will give satisfactory readings. To avoid large errors due to small samples, volumes of aliquots must be measured very carefully. Some idea as to the degree of precision and accuracy of the methods is given in table 2.

TABLE 2

*Recovery of elements from mixed solutions by rapid procedures*

| ELEMENT* | AMOUNT DETERMINED† | | | AMOUNT PRESENT |
|----------|------|------|------|----------------|
|          | Low  | High | Mean |                |
|          | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| N        | 9.2  | 11.5 | 10.0 | 10 |
| P        | 4.9  | 5.4  | 5.2  | 5  |
| K        | 23.0 | 25.6 | 24.2 | 25 |
| Ca       | 28.3 | 32.8 | 31.4 | 30 |
| Mg       | 2.3  | 3.1  | 2.7  | 2.5 |

* 5 p.p.m. of N from ammonium sulfate and 5 p.p.m. from sodium nitrate, P from monosodium phosphate, K from potassium chloride, Ca from calcium acetate, dihydrate, Mg from magnesium sulfate, tetrahydrate.

† Results of eight separate determinations.

### APPLICATION OF RAPID ANALYSIS IN DETERMINING FERTILITY NEEDS OF SPINACH

*Experimental procedure*

Two different series of test plots were used. Each plot was 0.02 acre, and treatments were replicated three times in each location. One series of plots established on Sassafras gravelly sandy loam soil, hereafter designated as "Eastern plots," has been under intensive vegetable production for about 12 years. The pH of this soil was about 6.5, and the organic matter content was 1.4 per cent. The other series of plots, established on Sassafras loam and hereafter designated as "Deerfield plots," has been under intensive vegetable production for about 5 years. At the start of the experiment, the pH of this soil was 5.8 and the organic content 1.8 per cent.

The amounts of ammonium nitrate, 20 per cent superphosphate, and 61 per cent muriate of potash applied to the plots were varied so as to keep two of the major fertilizer nutrients constant while the third varied. When constant, the amounts of nutrients per acre were as follows: N, 180 pounds; $P_2O_5$, 180 pounds; $K_2O$, 120 pounds. These nutrients, supplied by 1,500 pounds of

## TABLE 3

*Composition of soil and spinach as influenced by various fertilizer treatments and measured by rapid soil and plant tests—Deerfield plots*

| NUTRIENT* APPLIED (lbs./A.) | | | N Soil Soluble (lbs.†) | | N Plant Soluble (p.p.m.‡) | | N Plant Total (per cent) | | P Soil Soluble (lbs.†) | | P Plant Soluble (per cent) | | P Plant Total (per cent) | | K Soil Soluble (lbs.†) | | K Plant Soluble (per cent) | | K Plant Total (per cent) | | FRESH WEIGHT OF SPINACH (tons/A.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | $P_2O_5$ | $K_2O$ | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | |
| 30 | 180 | 120 | 34 | 16 | 480 | 2800 | 4.4 | 4.0 | 15 | 16 | 0.39 | 0.60 | 0.56 | 0.77 | 170 | 160 | 6.1 | 7.5 | 5.5 | 7.3 | 4.8 |
| 60 | 180 | 120 | 33 | 21 | 820 | 2000 | 4.4 | 4.5 | 15 | 14 | 0.33 | 0.48 | 0.54 | 0.70 | 150 | 150 | 5.8 | 6.8 | 5.4 | 6.8 | 6.0 |
| 120 | 180 | 120 | 84 | 35 | 880 | 3600 | 4.9 | 5.8 | 16 | 14 | 0.32 | 0.44 | 0.52 | 0.63 | 195 | 110 | 5.1 | 5.0 | 4.8 | 5.5 | 7.5 |
| 180 | 180 | 120 | 140 | 62 | 1300 | 4100 | 4.9 | 5.6 | 14 | 13 | 0.23 | 0.38 | 0.51 | 0.55 | 135 | 125 | 4.8 | 5.1 | 4.7 | 5.2 | 8.0 |
| 240 | 180 | 120 | 121 | 132 | 1020 | 3700 | 5.0 | 5.9 | 14 | 12 | 0.21 | 0.32 | 0.48 | 0.50 | 175 | 150 | 4.9 | 4.9 | 4.9 | 5.2 | 7.8 |
| 180 | 60 | 120 | 103 | 43 | 840 | 1870 | 5.2 | 6.9 | 12 | 13 | 0.26 | 0.40 | 0.51 | 0.57 | 170 | 110 | 5.4 | 5.9 | 5.3 | 5.7 | 8.0 |
| 180 | 120 | 120 | 73 | 20 | 1000 | 1810 | 4.6 | 5.6 | 13 | 14 | 0.33 | 0.44 | 0.52 | 0.58 | 180 | 140 | 5.4 | 5.8 | 5.4 | 5.7 | 7.5 |
| 180 | 240 | 120 | 63 | 24 | 880 | 2000 | 4.8 | 5.2 | 16 | 16 | 0.31 | 0.52 | 0.53 | 0.60 | 190 | 120 | 5.4 | 5.3 | 5.6 | 5.6 | 8.0 |
| 180 | 180 | 40 | 53 | 26 | 920 | 1680 | 5.0 | ... | 16 | 13 | 0.33 | 0.40 | 0.53 | 0.56 | 150 | 105 | 5.4 | 4.8 | 5.4 | 5.2 | 6.4 |
| 180 | 180 | 80 | 40 | 20 | 1140 | 1770 | 4.2 | 5.2 | 13 | 13 | 0.30 | 0.40 | 0.51 | 0.56 | 140 | 110 | 5.6 | 5.6 | 5.6 | 5.8 | 8.1 |
| 180 | 180 | 160 | 40 | 33 | 820 | 1820 | 4.6 | 4.7 | 13 | 13 | 0.26 | 0.40 | 0.49 | 0.60 | 165 | 115 | 5.9 | 6.0 | 5.9 | 6.3 | 7.4 |
| 180 | 180 | 200 | 45 | 20 | 1200 | 1500 | 4.7 | 4.4 | 13 | 13 | 0.26 | 0.44 | 0.50 | 0.66 | 185 | 125 | 6.4 | 6.5 | 6.2 | 6.6 | 8.6 |
| 100 | 100 | 100 | 61 | 22 | 860 | 2100 | 4.8 | 5.5 | 14 | 12 | 0.31 | 0.44 | 0.54 | 0.65 | 150 | 115 | 5.2 | 4.7 | 5.1 | 4.7 | 7.7 |
| 80 | 60 | 40 | 35 | 17 | 580 | 1800 | 5.1 | 4.4 | 11 | 12 | 0.37 | 0.50 | 0.54 | 0.76 | 150 | 100 | 5.5 | 6.2 | 5.3 | 5.9 | 4.7 |
| 240 | 240 | 200 | 111 | 73 | 1300 | 5300 | 5.0 | 5.9 | 14 | 13 | 0.29 | 0.40 | 0.51 | 0.58 | 175 | 160 | 5.6 | 5.0 | 5.2 | 5.0 | 9.0 |
| 0 | 0 | 0 | 32 | 11 | 400 | 3200 | 4.4 | 3.7 | 12 | 13 | 0.38 | 0.64 | 0.52 | 0.78 | 150 | 100 | 5.0 | 3.4 | 5.1 | 6.3 | |

* N from ammonium nitrate, $P_2O_5$ from 20 per cent super phosphate; $K_2O$ from 61 per cent muriate of potash.

† Results expressed in pounds of the element per 2,000,000 pounds air-dried soil; (a) sampled October 15, 1946; (b) sampled November 7 1946.

‡ p.p.m. and percentages on a dry-weight basis. Time of sampling same as for soil.

## TABLE 4

*Composition of soil and spinach as influenced by various fertilizer treatments and measured by rapid soil and plant tests—Eastern plots*

| NUTRIENT APPLIED | | | N | | | | | | P | | | | | | K | | | | | | FRESH WEIGHT OF SPINACH |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | Soil Soluble | | Plant Soluble | | Plant Total | | Soil Soluble | | Plant Soluble | | Plant Total | | Soil Soluble | | Plant Soluble | | Plant Total | | |
| N | P₂O₅ | K₂O | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | |
| lbs./A | | | lbs.† | | p.p.m.‡ | | per cent | | lbs.† | | per cent | | per cent | | lbs.† | | per cent | | per cent | | tons/A. |
| 30 | 180 | 120 | 23 | 18 | 640 | 1025 | 4.2 | 4.0 | 26 | 29 | 0.33 | .. | 0.67 | 0.84 | 170 | 165 | 8.5 | 6.7 | 8.5 | 6.3 | 4.7 |
| 60 | 180 | 120 | 26 | 16 | 1460 | 1560 | 4.6 | 5.0 | 35 | 27 | 0.44 | 0.54 | 0.67 | 0.70 | 180 | 135 | 8.4 | 6.3 | 8.5 | 6.3 | 7.0 |
| 120 | 180 | 120 | 26 | 23 | 1830 | 2400 | 4.8 | 5.4 | 31 | 30 | 0.38 | 0.46 | 0.62 | 0.64 | 200 | 140 | 8.2 | 5.9 | 8.5 | 5.6 | 8.0 |
| 180 | 180 | 120 | 30 | 60 | 2250 | 3790 | 5.1 | 6.0 | 21 | 21 | 0.37 | 0.39 | 0.61 | 0.54 | 180 | 135 | 8.0 | 5.2 | 8.1 | 5.7 | 7.6 |
| 240 | 180 | 120 | 40 | 44 | 2200 | 3600 | 4.8 | 5.6 | 22 | 23 | 0.36 | 0.41 | 0.57 | 0.58 | 165 | 125 | 7.8 | 4.9 | 8.1 | 5.2 | 7.7 |
| 180 | 60 | 120 | 20 | 23 | 1940 | 2360 | 5.1 | 5.1 | 21 | 23 | 0.40 | 0.41 | 0.62 | 0.58 | 170 | 120 | 8.6 | 5.6 | 8.5 | 5.6 | 8.0 |
| 180 | 120 | 120 | 30 | 12 | 1400 | 1230 | 4.5 | 5.3 | 26 | 27 | 0.39 | 0.57 | 0.64 | 0.75 | 180 | 135 | 7.8 | 6.3 | 8.8 | 5.7 | 7.2 |
| 180 | 240 | 120 | 38 | 16 | 2000 | 2290 | 4.6 | 4.5 | 28 | 33 | 0.41 | 0.49 | 0.64 | 0.65 | 170 | 130 | 8.2 | 5.4 | 8.1 | 5.6 | 7.7 |
| 180 | 180 | 40 | 35 | 12 | 1650 | 1630 | 4.9 | 4.9 | 23 | 29 | 0.41 | 0.52 | 0.64 | 0.68 | 155 | 135 | 8.0 | 5.7 | 8.1 | 5.8 | 7.2 |
| 180 | 180 | 80 | 41 | 13 | 2000 | 1030 | 4.5 | 4.7 | 21 | 24 | 0.36 | 0.50 | 0.62 | 0.65 | 175 | 126 | 9.0 | 6.1 | 8.4 | 5.6 | 7.8 |
| 180 | 180 | 160 | 36 | 12 | 2000 | 1450 | 4.5 | 5.0 | 29 | 28 | 0.36 | 0.50 | 0.59 | 0.65 | 180 | 135 | 9.2 | 5.8 | 8.8 | 5.4 | 7.7 |
| 180 | 180 | 200 | 45 | 18 | 2010 | 1010 | 4.5 | 5.1 | 27 | 26 | 0.35 | 0.52 | 0.62 | 0.70 | 215 | 170 | 8.2 | 6.8 | 8.8 | 6.0 | 7.9 |
| 100 | 100 | 100 | 37 | 17 | 1730 | 1760 | 4.5 | 5.3 | 22 | 22 | 0.39 | 0.48 | 0.63 | 0.64 | 140 | 100 | 7.8 | 6.0 | 8.1 | 5.4 | 7.3 |
| 30 | 60 | 40 | 16 | 11 | 1020 | 1200 | 4.5 | 4.1 | 23 | 23 | 0.41 | 0.60 | 0.64 | 0.76 | 135 | 120 | 8.4 | 5.3 | 8.5 | 5.0 | 4.3 |
| 240 | 240 | 200 | 86 | 32 | 2370 | 2430 | 5.2 | 5.9 | 24 | 28 | 0.39 | 0.41 | 0.64 | 0.59 | 190 | 150 | 8.0 | 5.6 | 8.8 | 6.0 | 8.8 |
| 0 | 0 | 0 | 21 | 11 | 1310 | 1300 | 4.4 | 2.9 | 29 | 19 | 0.39 | .. | 0.64 | 0.82 | 140 | 135 | 8.0 | 5.5 | 7.2 | 5.4 | .. |

* N from ammonium nitrate; P₂O₅ from 20 per cent superphosphate; K₂O from 61 per cent muriate of potash.

† Results expressed in pounds of the element per 2,000,000 pounds air-dried soil; (a) sampled October 15, 1946; (b) sampled November 9, 1946.

‡ p.p.m and percentages on dry-weight basis. Time of sampling same as for soil.

4-12-8 plus 400 pounds cyanamid and 200 pounds of sodium nitrate per acre, have been standard fertilizer for spinach on these soils for some time. In addition to treatments where two of the nutrients were constant, three treatments in which all three nutrients were variable were included in each series to note effect on yield and composition of low, medium, and high levels of nitrogen, phosphoric acid, and potash. The treatments along with other data are listed in tables 3 and 4.

Four hundred pounds of 4-12-8 fertilizer was applied per acre directly to a cover crop of rye grass in the Eastern plots and to rye in the Deerfield plots and

TABLE 5

*Nutrients removed in tops of spinach as influenced by fertilizer treatment*

| NUTRIENTS APPLIED | | | NUTRIENTS REMOVED | | | | | |
| | | | N | | $P_2O_5$ | | $K_2O$ | |
| N | $P_2O_5$ | $K_2O$ | Eastern plots | Deerfield plots | Eastern plots | Deerfield plots | Eastern plots | Deerfield plots |
|---|---|---|---|---|---|---|---|---|
| lbs./A. | lbs./A. | lbs./A. | lbs./A. | lbs./A. | lbs./A. | lbs./A. | lbs./A. | lbs./A. |
| 30 | 180 | 120 | 38 | 38 | 18 | 15 | 59 | 70 |
| 60 | 180 | 120 | 70 | 54 | 22 | 18 | 88 | 82 |
| 120 | 180 | 120 | 86 | 87 | 22 | 20 | 90 | 82 |
| 180 | 180 | 120 | 91 | 90 | 18 | 20 | 87 | 83 |
| 240 | 180 | 120 | 86 | 92 | 20 | 18 | 80 | 81 |
| 180 | 60 | 120 | 82 | 110 | 20 | 20 | 90 | 91 |
| 180 | 120 | 120 | 76 | 83 | 21 | 20 | 82 | 86 |
| 180 | 240 | 120 | 69 | 83 | 22 | 20 | 86 | 90 |
| 180 | 180 | 40 | 70 | | 22 | 15 | 83 | 67 |
| 180 | 180 | 80 | 73 | 84 | 22 | 20 | 87 | 94 |
| 180 | 180 | 120 | 77 | 70 | 22 | 20 | 83 | 93 |
| 180 | 180 | 200 | 80 | 76 | 24 | 24 | 95 | 113 |
| 100 | 100 | 100 | 77 | 85 | 18 | 22 | 79 | 72 |
| 30 | 60 | 40 | 35 | 41 | 15 | 15 | 43 | 55 |
| 240 | 240 | 200 | 103 | 106 | 22 | 22 | 106 | 90 |

plowed under. The plots were planted to Wilson soybeans. Fertilizer treatments as given in tables 3 and 4 were applied August 17 to the soybeans. The soybeans were plowed under August 23 in the Eastern plots and August 27 in the Deerfield plots. The land was fitted and Virginia Blight Resistant Savoy spinach was planted in the Deerfield plots August 31 and in the Eastern plots September 5.

Samples of soil and spinach leaves were taken in both areas October 14. At that time distinct differences in growth and color on nitrogen series were visible. Five borings of soil taken with an auger from each plot were composited as a single sample. The entire leaves from approximately 20 plants in each plot were composited as a single sample. Sampling according to this procedure was repeated at harvest time (November 7 in Deerfield plots and November 9 in Eastern plots).

Soil and plants were analyzed by rapid methods. Soluble nutrients were determined on oven-dried finely ground samples rather than on fresh samples because of convenience in handling large numbers of samples. Results of analysis for nitrogen, phosphorus, and potassium and yields for Deerfield plots are given in table 3 and those for Eastern plots in table 4. Results are averages of three determinations for each treatment. Amounts of nutrients removed on an acre basis are given in table 5.

## Results

### Yield

Yields of spinach as indicated in tables 3 and 4 show marked responses to nitrogen applications up to about 180 pounds per acre, responses to potash up to 80 pounds, and no response to phosphoric acid. Applications of 100 pounds each of nitrogen, phosphoric acid, and potash were as satisfactory as 100 pounds of nitrogen with higher amounts of phosphoric acid and potash. These results indicate that marked economies in fertilizer application can be made by reducing phosphoric acid and potash applications to take into consideration the already existing high levels of these nutrients.

It is of interest that response to the largest application (240 pounds per acre) of nitrogen was obtained on soils receiving the most phosphoric acid and potash. This would indicate that greater amounts of nitrogen than 180 pounds can be utilized only in the presence of large quantities of minerals. Since no response to phosphorous was obtained at lower nitrogen levels, it is believed that amounts of potash above 120 pounds per acre were largely responsible for the increased yield at higher levels of nitrogen.

### Nitrogen

There was an association between amounts of nitrogen applied to the soil and nitrogen in the soil or plant for any one sampling date at one location. The amounts of soluble nitrogen in the soil decreased in both locations at the second sampling date while amounts of soluble nitrogen within the plant increased. The amounts of total nitrogen in the plant increased with time for most treatments. Notable exceptions were plots receiving no nitrogen or small amounts of nitrogen. At harvest time, amounts of total nitrogen in plants from the Deerfield plots tended to decrease as applied phosphoric acid or potash increased. Such trends were not apparent in plants from the Eastern plots.

From the data presented, it is difficult to establish absolute minimum values for soluble nitrogen in soil or plant or total nitrogen in the plant that are consistent with good yields. Rather there seem to be certain levels of nitrogen in these forms which are associated with good yields. There are exceptional cases producing good yields at much lower levels, and these levels vary with the time of sampling. For example, in the Deerfield plots, soils having more than 40 pounds of soluble nitrogen per 2,000,000 pounds of soil at the first sampling date supported high yields of spinach. There were plots, however, with good yields but having smaller amounts of soluble nitrogen. At harvest time, amounts of

soluble nitrogen greater than 30 pounds were associated with high yields. In the Eastern plots, levels associated with good yields were appreciably lower: about 30 pounds at first sampling date and 20 pounds at harvest time.

The correlation between soil nitrogen and yield may have been better at some earlier date. The amount remaining in the soil even on October 15 was already markedly affected by plant uptake as well as leaching. Therefore, a lower value of soil nitrogen on October 15 may be a reflection of considerable influence on plant growth. From a practical standpoint, earlier sampling dates would tend to yield much more useful information.

The soluble nitrogen in the plant was also associated with yield, but again it was impossible to establish basal minimum values. In plants from the Deerfield plots, more than 1,000 p.p.m., on a dry-weight basis, of soluble nitrogen at the first sampling date was associated with good yields. For plants in the Eastern plots, this amount would be closer to 1,500 p.p.m. Again there were notable exceptions of plants having less nitrogen than these values and giving good yields. The data for soluble nitrogen at harvest time were somewhat more inconsistent but with lower limits for good yields—about 2,000 p.p.m. on a dry-weight basis.

The values for total nitrogen in the plant also varied with time of sampling and fertilizer treatment. Contents higher than 5.0 per cent on a dry-weight basis at harvest time were associated in both areas with good yields. The percentages of nitrogen tended to increase with age except for plots receiving little or no nitrogen. There was a tendency for total nitrogen in the plant to decrease as phosphorus or potash applications were increased. The amounts of nitrogen removed per acre varied with different treatments, the largest amounts being slightly over 100 pounds per acre. Only with small applications of nitrogen did plants remove more nitrogen than was applied.

*Phosphorus*

Data pertinent to phosphorus are difficult to interpret because of lack of response to applied phosphoric acid. There was considerable variation in soluble phosphorus in the soil for any one treatment. Nevertheless, there was a trend toward increased soil phosphorus with large applications of phosphorus. The over-all average of Eastern plots was considerably higher than that of Deerfield plots. This evidently was a reflection of the larger amounts of phosphorus previously applied to the site of the Eastern plots. Since there was no response to phosphorus, it must be assumed that a test of 12 pounds of soluble phosphorus per 2,000,000 pounds of soil is ample for a spinach crop. This is consistent with previous results for spinach which have shown no response to added phosphorus when the soil test was 10 or more pounds of soluble phosphorus per 2,000,000 pounds of soil.

The amounts of phosphorus in the plant tended to vary inversely with nitrogen applied to the soil and directly, but to a lesser degree, with phosphorus.

In plants from both plot areas, the amounts of soluble and total phosphorus increased with age. The amounts present in plants of Eastern plots were

generally higher than similarly treated plants from Deerfield plots. This is undoubtedly a reflection of the higher soluble phosphorus content in the Eastern soil.

Amounts of phosphorus removed by the spinach crop are small. Since there are already large amounts present in both these soils, only small annual applications are needed to maintain the supply. Great economies in fertilizer application can be made by reducing phosphorus applications on such soils.

*Potassium*

There was an indication of response to potassium, but additions of 80 pounds of potash per acre gave as good yields as larger amounts. As with soluble soil phosphorus, there was considerable variation in soil potassium within plots receiving equal amounts of potash. Nevertheless, there was a definite indication that ample potash was present if the soil contained about 170 pounds of soluble potassium per 2,000,000 pounds at the first sampling date. At harvest time, amounts greater than 135 pounds per 2,000,000 pounds of soil were associated with good yields. Smaller amounts were not necessarily associated with poor yields, but there was such a tendency.

Potassium within the plant also varied directly with potassium applications and inversely with nitrogen applications to the soil. The addition of potassium to the soil was associated with marked changes in the potassium content of the plant. The much lower potassium content of tops of plants receiving large amounts of nitrogen was an indication of possible deficiency brought about by large nitrogen applications. From a practical standpoint, it is possible that amounts of potash applied should be varied in accordance with amounts of nitrogen used.

The potassium content of plants from Deerfield plots generally increased with age except for a few plots receiving no potash or only small amounts. Plants from Eastern plots showed a general decrease in potassium with age.

Approximately 100 per cent of the total potassium in the plant was extractable in dry soluble form. Results indicating more potassium in dry soluble form than was present as total potassium are evidently due to errors of the method in determining such high potassium contents.

Potash removed per acre varied somewhat with the amount applied. At standard applications of 120 pounds per acre, approximately 90 pounds was removed. Use of only 80 pounds potash per acre, which gave maximum yields, would evidently soon deplete available supplies if good yields were maintained.

### DISCUSSION

The methods presented in this paper were useful in helping to establish nutrient status of soils and spinach plants. With a precision of only ± 10 per cent, they were nevertheless able to pick out certain basic trends in nutrition. Where a large number of samples are being determined and averaged, there is sufficient precision to allow a fairly good appraisal of nutrient content. The speed with

which analyses can be made by this system allows a great number of samples to be run in a short time. The system, therefore, is useful in the fact that the results from a large number of samples can give certain basic facts. The data as presented in this single study showed the interrelationships of various nutrients in the soil and in the plant and gave some indication of the changes that took place with time and different fertilizer treatments.

From the data presented, it was possible to select certain levels of nutrients present in the soil or plant which were associated with good growth. These levels varied with sampling date and were more definite for soil nutrients. There was an indication that some plants gave good yields despite low nutrient levels, but all plants with higher nutrient contents than base levels were always associated with good yields. Since time of sampling may give different results, it is important from a practical standpoint that such levels be determined for various periods.

The results obtained from the three general procedures (rapid tests for soluble nutrients in soils and in plants and for total nutrients in plants) have considerable value in supplementing information on fertilization, but all three procedures seem to have limitations. From the standpoint of answering the question as to how much or what kind of fertilizer to use, the soil tests would appear to have an advantage. It seems possible to establish levels of various nutrients necessary to produce a good yield of a crop. To determine these levels, sampling would have to be made before fertilization and directly after fertilizer had been worked into the soil. The levels of nutrients after fertilization could then be correlated with yields, and certain minimums for good crops selected. The degree of change from one level to another could then be used in practice to determine the amounts and kinds of fertilizer required for any particular field.

Such development of minimum levels and the amounts of fertilizer necessary to reach them would vary for each crop grown on certain soils in a particular region. Much correlation is needed, therefore, before a particular set of procedures can be used to full advantage.

From data presented it is doubtful whether the plant analysis, with exception of soluble nitrogen, can be of as much help in practical estimation of fertility needs of individual fields of spinach. In general, the results are obtained too late. Also, interpretation is difficult because of variation due not only to the element studied but to other fertilizer applied and because of variability with age of the plant. This information is useful, however, in determining amounts of nutrients removed by crops, in noting changes of nutrients within the crop, and in conjunction with soil analysis in determining causes of crop failure.

The soluble nitrogen within the spinach plant did not seem to be markedly affected by the presence of the other major elements. Nitrogen applications as side-dressings can be made in ample time to effect substantial change in growth. Before such information can be used intelligently a very close study needs to be made of the influence of age upon concentration of nitrogen within the plant.

## SUMMARY

A system of rapid tests for soluble nutrients in soils and in plants and for total nutrients in plants is presented. Advantages of the system are use of common reagents and procedures and adaptation to readings by photoelectric colorimeter with similar standard curves for any nutrient in the three categories.

A study of the nutrition of fall-grown spinach by means of this system was made by sampling soil and plants approximately 6 weeks after planting and also at harvest time. The study has brought out the following facts:

Spinach grown on two different types of Sassafras soil which had been intensively fertilized for years responded markedly to applications of ammonium nitrate, only slightly to muriate of potash, and not at all to superphosphate.

There was a definite association between nitrogen applications and soluble nitrogen in the soil, and between soluble nitrogen and total nitrogen in the plant at two different sampling dates.

The amounts of nitrogen in one of three forms varied with sampling dates. Soluble nitrogen in the soil decreased as plants matured, whereas soluble or total nitrogen in tops of plants tended to increase with age.

It was difficult to establish basal minimums for each category. Soil nitrogen in amounts above 30 to 40 pounds per acre at first sampling date and 20 to 30 pounds per acre at second sampling date was associated with good yields. The corresponding value for soluble nitrogen in the plant was 1,000 to 1,500 p.p.m. on a dried basis at first sampling date. The percentages for total nitrogen were also difficult to correlate with yields, though percentages of N above 5.0 on a dry-weight basis were generally associated with good yields.

Soluble phosphorus in the soil in amounts greater than 12 pounds per acre was evidently sufficient for spinach. The concentration of phosphorus within the plant tended to increase with phosphorus additions to soil and to decrease with nitrogen additions. Concentrations within the plant increased with age of the plant.

About 170 pounds of soluble potassium in the soil at first sampling date seemed to be ample for spinach. Concentrations of potassium within the plant varied directly with potassium additions to soil and inversely with amounts of nitrogen added. The effect of age upon concentration varied at two different locations.

Because of variability of phosphorus and potassium in the plant, due to other causes than the availability of these elements in the soil, the usefulness of plant analysis as a practical guide to fertilization of spinach is limited. Nitrogen analysis of the plant seems to have more value. Studies as reported here have value, however, in determining the course of nutrition and fertility needs. Rapid soil analysis using an early sampling date seems to have more practical value in estimating fertility needs of the spinach crop. There is need for establishment of levels of soil nutrients which are consistent with good yields followed by attempts to supply such nutrients.

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# SOIL ORGANIC NITROGEN: II. SOME STUDIES ON THE AMINO ACIDS OF PROTEIN MATERIAL IN A MUCK SOIL FROM GENEVA, NEW YORK

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In a previous paper on the nature of soil organic nitrogen in muck soil from Geneva, New York (3), the amino acid character of a considerable part of the organic nitrogen of the hydrolysis products was confirmed by decarboxylation with ninhydrin. It was reported that 37 per cent of the total nitrogen of the muck was present as α-amino nitrogen after hydrolysis. Although small quantities of various amino acids have been isolated as hydrolysis products of soil organic matter, no attempt has been made to account for the total amino nitrogen of soil hydrolyzates by a quantitative estimation of the individual amino acids. The purpose of the present investigation was to identify and determine quantitatively, as far as possible, the individual amino acids derived from soil protein by hydrolysis and to ascertain whether or not there may be some striking feature in the distribution of amino acids in soil proteins. It was hoped that with recent developments in the field of amino acid and analysis, some of the new techniques might be applied to the determination of amino acids in soil proteins. The pertinent literature on the amino acids of soil protein material was reviewed in the previous paper (3).

As a starting point in these studies, the monoamino acids were investigated, since they constitute about 90 per cent of the total amino nitrogen in hydrolyzates of the muck soil from Geneva, New York, and also account for a similar percentage in other soils.

## EXPERIMENTAL

### Isolation and determination of aspartic acid

The refined Foreman method of Bailey et al. (1) for the determination of the dicarboxylic amino acids was applied with slight modification to the determination of aspartic acid in hydrolyzates of the muck. The scheme of analysis showing the modifications appears on following page.

A 600-gm. sample of moist muck was hydrolyzed with 2 liters of concentrated HCl for 24 hours. The acid hydrolyzate containing 1.678 gm. of amino nitrogen[2] was carried through the procedure outlined above, the details of operation described by Bailey et al. (1) being observed. According to these authors, the cuprous oxide treatment in step 3 precipitates mercaptides the dismutation products of which interfere with subsequent crystallization of copper aspartate.

[2] Determined by the nitrous acid method after removal of humin and NH₃ (at 100°).

1                2                    3                        4
Hydrolysis → Removal of HCl → Treatment with Cu₂O → Filtrate freed of Cu

Hydrolysis $\rightarrow$ Removal of HCl $\rightarrow$ Treatment with $Cu_2O$ $\rightarrow$ Filtrate freed of Cu

5                          6                          7
Lime-ethanol treatment $\rightarrow$ Ca removed from precipitate $\rightarrow$ Filtrate boiled with $CuCO_3$

8                                      9
Filtrate boiled with Darco $\rightarrow$ Isolation of Cu aspartate (first and main crop)

10                                          11
Filtrate boiled with Darco, concentrated in vacuo $\rightarrow$ Cu aspartate (second crop)

12                                      13b
2 volumes ethanol added to filtrate, filtered $\rightarrow$ Ethanol removed from filtrate

$\downarrow$                                          $\downarrow$

13a                                      14b
Water added to precipitate, filtered          Cu aspartate (third crop)

$\downarrow$

14a
Cu aspartate (fourth crop) from filtrate

It was the writer's experience that the cuprous oxide treatment removed only part of the interfering materials in the soil hydrolyzate. Even after repeated treatment with cuprous oxide, there remained in solution material which slowly precipitated as a green scum along with copper aspartate. Treatment of the copper solution with Darco in step 8 removed most of the interfering material with only slight loss of nitrogen, and copper aspartate then crystallized rapidly from the deep-blue solution as clusters of needles. The filtrate from the first crop of copper aspartate, also greenish in color, yielded more copper aspartate after further treatment with Darco.

The copper aspartate precipitates contained a total of 118.8 mgm. nitrogen. The percentage nitrogen of the combined air-dry copper aspartate was 5.35. The total copper aspartate isolated accounts for 7.08 per cent of the total amino nitrogen of the muck hydrolyzate. In another experiment, 6.38 per cent of the total amino nitrogen of the hydrolyzate was found in the copper aspartate precipitate. The percentages of total amino nitrogen accounted for as aspartic acid by isolation of copper aspartate are in accord with the calculated value of 6.98 per cent which was previously determined from the difference between amino nitrogen values obtained by the decarboxylation method and the nitrous acid method (3).

Free aspartic acid was isolated from the combined copper aspartate precipitate after removal of copper with $H_2S$. The aspartic acid solution was evaporated to dryness. The product was crystallized once from 50 per cent ethanol and twice from water. The amino acid was identified as aspartic acid by the crystal constants[3] found: Ng = 1.63, Np = 1.51. Values cited in the literature for the crystal constants (6) are Ng = 1.630, Np = 1.515. The nitrogen content found was 10.57 per cent; calculated, 10.52 per cent.

### Glutamic and hydroxy glutamic acid

The dicarboxylic acid fraction of hydrolyzates of the muck contains about 25 per cent of the total amino nitrogen. About 25 to 30 per cent of the amino

[3] Kindly determined by S. B. Hendricks.

nitrogen in the dicarboxylic acid fraction is accounted for as aspartic acid. The nature of the remaining amino nitrogen in the dicarboxylic acid fraction is still obscure, although some evidence for the presence of glutamic and hydroxy glutamic acid has been obtained. Numerous attempts to isolate glutamic acid as the hydrochloride were unsuccessful. An indirect method of determining glutamic and hydroxy glutamic acid was therefore investigated. The loss of amino nitrogen in the conversion of glutamic acid to pyrrolidonecarboxylic acid has been used as a quantitative measure of small amounts of glutamic acid in solution (4). Hydroxy glutamic acid undergoes anhydride formation even more rapidly than does glutamic acid.

The method was applied to the dicarboxylic acid fraction of the muck hydrolyzate after separation of most of the aspartic acid as the copper salt by the method previously described. The solution of copper salts after removal of copper aspartate was treated with $H_2S$ to liberate the free acids for analysis.

The determination was carried out as follows:

The amino acid solution was brought to pH 3.3 with dilute NaOH by means of the glass electrode. The solution was autoclaved for 4 hours at a pressure of 119 pounds per square inch. Amino nitrogen was determined before and after autoclaving by the nitrous acid method.

The average conversion of pure glutamic acid to pyrrolidonecarboxylic acid by this method was 87.38 per cent. Glutamic and hydroxy glutamic acid nitrogen in the dicarboxylic acid fraction of the muck was taken as the amino nitrogen lost by autoclaving after correction for the conversion factor.

The results of the determination on 25-ml. aliquots of solution from the dicarboxylic acid fraction (minus aspartic acid) were as follows:

|  | AMINO NITROGEN mgm. |
| --- | --- |
| Before autoclaving | 20.83 |
| After autoclaving | 15.25 |
| Loss by autoclaving | 5.58 |
| Corrected glutamic and hydroxy glutamic acid | 6.39 |

The total amino nitrogen of the dicarboxylic acid fraction before removal of aspartic acid was 30.08 mgm. per 25 ml.

The glutamic and hydroxy glutamic acid nitrogen determined accounts for 21.24 per cent of the amino nitrogen in the dicarboxylic acid fraction and approximately 5 per cent of the total amino nitrogen of the soil hydrolyzate.

Only a trace of ammonia was detected in the autoclaved solution. This indicates that deamination of other amino acids in the soil fraction was negligible.

Aspartic and glutamic (and hydroxy glutamic) acids as determined in the preceding experiments account for about 46 to 51 per cent of the total amino nitrogen in the dicarboxylic acid fraction. The nature of the remaining amino acids in this fraction is undetermined.

### Hydroxy amino acids

Hydroxy amino acids in the hydrolyzate of the muck were determined by the periodate method (5). Humin and $NH_3$ (at 100°) were first removed from the

hydrolyzate in the usual manner. The ammonia liberated in the reaction with periodate accounted for 18 per cent of the total amino nitrogen. Hydroxy amino acids often found in proteins are threonine, serine, hydroxy glutamic acid, and hydroxy lysine.

### Isolation of leucine, isoleucine, and valine

The amino acids remaining as soluble calcium salts, after separation of the dicarboxylic acids by the Foreman method, constitute approximately 75 per cent of the total amino nitrogen of the muck hydrolyzate. Small quantities of leucine and isoleucine were isolated from this fraction as copper salts after much laborious manipulation. It was later discovered that the amino acids could be more readily isolated by effecting an initial separation of crude amino acid fractions from the solution. The procedure developed for the isolation of leucine, isoleucine, and valine is described in detail below with procedures for the general preparation of soil hydrolyzates for amino acid isolations.

*Hydrolysis of soil protein.* A 500-gm. sample of air-dry, finely ground muck was refluxed 48 hours with 2 liters of 20 per cent HCl. The acid mixture from two batches or from 1,000 gm. of soil was filtered through a large sintered-glass funnel. The insoluble residue in the funnel was washed repeatedly with hot $N$ HCl. The residue was further washed by suspension in dilute HCl. The washing by suspension was repeated until the filtrate was nearly colorless (two or three washings in this manner were usually sufficient).

*Removal of HCl, inorganic salts, and gum.* The combined filtrate was evaporated at 50–60° under reduced pressure to a thick sirup. Calcium sulfate separated during the distillation but was not removed, and 10 $N$ $H_2SO_4$ was added to the sirup until no further precipitation of calcium sulfate was apparent. Care was taken to avoid adding too large an excess of sulfuric acid, since its subsequent removal as barium sulfate entails loss of nitrogen. The calcium sulfate was filtered on a sintered-glass funnel and washed with small portions of water. The filtrate was evaporated to a sirup under reduced pressure. Any calcium sulfate separating out during the distillation was filtered off and washed. The last traces of free HCl remaining in the sirup were removed as completely as possible by repeated additions of water followed by evaporation to a thick sirup.

The sirup was taken up with 400 cc. of 50 per cent ethanol. Some inorganic salts and a sticky dark gum separated. The solution was chilled and filtered. The precipitate was washed with cold 50 per cent ethanol and the washings were combined with the main filtrate.

*Precipitation of humin and removal of ammonia.* Ethanol was distilled from the combined filtrate under reduced pressure. Excess cream of lime was added and the precipitate filtered off on a Büchner funnel. The precipitate was thoroughly washed by repeated suspension in warm water. Ammonia was removed from the filtrate by distillation under reduced pressure at 50°, and the solution was further concentrated under these conditions to a light sirup (volume about 100 cc.).

*Precipitation of the dicarboxyl acid fraction.* The sirup was slowly poured into

9 volumes of 95 per cent ethanol with vigorous stirring. The insoluble calcium salts were filtered off at once on a Büchner funnel and washed with small portions of 95 per cent ethanol. The precipitate was sucked as dry as possible and dissolved in warm water. Some material did not dissolve, but without filtering, the solution was again poured into 9 volumes of 95 per cent ethanol. The precipitate was filtered off and washed with ethanol. The filtrate was added to the filtrate of the first lime-ethanol precipitation. Aspartic acid was readily isolated from the lime-ethanol precipitate as the copper salt after removal of calcium, chloride, and sulfate.

*Isolation of crude amino acid fractions.* The lime-ethanol solution was vacuum-distilled at 60° until ethanol was completely removed. Water was added to make the volume about 500 cc. Calcium was removed from the solution with oxalic acid. Chloride was next removed by triturating solid silver sulfate with the solution in a mortar. The mixture was transferred to a beaker and heated to granulate the silver chloride. The precipitate was filtered off and washed with hot water. Silver was removed from the filtrate with $H_2S$. After removal of $H_2S$ from the filtrate by vacuum-distillation for a short time, bases and much coloring matter were removed with phosphotungstic acid. Phosphotungstic acid solution was added until no further precipitation occurred. The solution was chilled and the precipitate filtered off and washed. Excess phosphotungstic acid and sulfate in the solution were removed with a slight excess of barium hydroxide solution. Barium was then quantitatively removed with dilute sulfuric acid. The solution was concentrated under reduced pressure until amino acids began to separate out as white solid material. The contents of the flask were transferred to a beaker with 50 per cent ethanol, and an equal volume of 95 per cent ethanol was added. Precipitation of amino acids was allowed to continue overnight in the refrigerator. The precipitate (fraction 1) was filtered off and washed with 50 per cent ethanol. The product obtained was white and granular in appearance, weighed 1.753 gm., and contained 10.98 per cent amino nitrogen.

The filtrate from fraction 1 was evaporated under reduced pressure until solid material separated out. The contents of the flask were transferred to a beaker with methanol. Two and a half volumes of absolute methanol were added to the solution. The precipitate was filtered off at once and washed with small portions of absolute methanol (fraction 2). The product was similar in appearance to fraction 1, weighed 1.271 gm., and contained 11.19 per cent amino nitrogen.

The filtrate from fraction 2 was evaporated to a thick sirup under reduced pressure and transferred to a beaker with absolute methanol. The methanol solution (125 cc.) was allowed to stand in the refrigerator for 2 days. The gelatinous precipitate was centrifuged off and washed with absolute methanol (fraction 3). The dry product was a pale yellow powder, weighing 2.750 gm., and contained 11.62 per cent amino nitrogen.

The methanol filtrate from fraction 3 was evaporated under reduced pressure to a thick gum. To this was added 150 cc. of water. Some dark gummy

material separated. The turbid solution was decanted from the gum and clarified with a little Darco. The filtrate, which was still somewhat orange in color, was evaporated under reduced pressure to a thick gum and granulated with 1:1 ethanol-acetone mixture. The precipitate (fraction 4) was centrifuged off and washed with ethanol-acetone and finally with anhydrous acetone. The product was dried in a vacuum desiccator over sulfuric acid and then over potassium hydroxide. The dry material was light brown and very hygroscopic. It weighed 4.250 gm. and contained 7.83 per cent amino nitrogen.

All the amino acid fractions left only traces of ash on ignition.

From the original lime-ethanol filtrate containing 2.324 gm. of amino nitrogen, a total of 0.9873 gm. of amino nitrogen was recovered in the four amino acid fractions. This corresponds to 42.5 per cent of the amino nitrogen in the lime-ethanol filtrate or approximately 31.9 per cent of the total amino nitrogen of the soil hydrolyzate. In another experiment, 55 per cent of the total amino nitrogen of the lime-ethanol filtrate was recovered in a single fraction by precipitation with ethanol and acetone. The amino nitrogen content of this product was 11.25 per cent.

*Isolation of leucine and isoleucine from fractions 1 and 2.* Fractions 1 and 2 were combined and dissolved in 50 cc. of water. The solution was boiled with excess copper carbonate and filtered hot. The copper salt of leucine precipitated on cooling. After 2 days at room temperature, the blue precipitate was filtered off and washed with water. The filtrate was set aside for later isolation of isoleucine.

The insoluble copper salt was dissolved in the smallest possible quantity of hot dilute HCl. Copper was precipitated from the solution with $H_2S$, and the filtrate was vacuum-distilled to dryness. The residue in the distilling flask was transferred with 10 cc. of water to a small beaker. One gram of naphthalene$\beta$-sulfonic acid dissolved in 5 cc. of warm water was added. The leucine salt of naphthalene$\beta$-sulfonic acid crystallized on cooling. Crystallization was allowed to continue at 0° for 2 days. The leucine nasylate was filtered off and washed with small portions of ice-cold water. The product was recrystallized very slowly from warm water as large rods and further recrystallized by dissolving in hot water and cooling to 0°. The leucine nasylate after drying over KOH *in vacuo* contained 3.95 per cent amino nitrogen (calculated for $C_6H_{13}O_2N \cdot C_{10}H_8O_3S \cdot H_2O$, 3.92 per cent amino nitrogen). The compound melted at 187–189° with decomposition (Maquenne block).

The copper salts soluble in water were evaporated to dryness under reduced pressure. The dry powdery residue was repeatedly extracted with cold absolute methanol until very little blue color was extracted. The methanol-insoluble residue was taken up in 25 cc. of water and the solution filtered from a small amount of insoluble material. The aqueous filtrate was again evaporated to dryness, the residue extracted with absolute methanol and then dissolved in water and filtered. These operations were repeated three times. The final water-soluble, methanol-insoluble copper salt fractionated in the above manner was decomposed with $H_2S$. The solution was evaporated to dryness and the

residue dissolved in hot 70 per cent methanol. The amino acid, presumably isoleucine, crystallized from the solution on cooling and standing in the refrigerator for 2 days. After two recrystallizations from 90 per cent ethanol, the crystals obtained were thin, greasy, hexagonal plates. The amino nitrogen content of the substance dried over sulfuric acid *in vacuo* was 10.55 per cent (calculated for isoleucine, 10.67 per cent).

*Isolation of valine.* Fraction 3 was dissolved in 50 cc. of water and converted to the copper salts. A small amount of insoluble copper salt which formed over 2 days' standing at room temperature was filtered off. The deep blue filtrate was evaporated to dryness under reduced pressure and the residue extracted twice with cold absolute methanol. The methanol solution was alternately evaporated to dryness and extracted with absolute methanol three times. The final methanol solution was evaporated to dryness and dissolved in water. Copper was removed from the solution with $H_2S$. The copper-free solution was evaporated to dryness *in vacuo*. The residue was dissolved in hot 80 per cent ethanol. Crystals separated on cooling. The amino acid was recrystallized twice from 80 per cent ethanol. The amino nitrogen content found was 10.94 per cent (calculated for valine, 10.98 per cent).

## DISCUSSION

The amino acids isolated from the muck hydrolyzates, namely, aspartic acid, leucine, isoleucine, and valine, are those one might expect to find in any of the plant and animal proteins. These amino acids are among those previously isolated from soil organic matter by other investigators and may indicate that the residual soil protein in organic matter long worked over by microorganisms tends to assume more or less a constant qualitiative composition with respect to amino acids. The complete absence of tryptophan in soil protein material was noted in the previous paper (3), and since no mention of tryptophan in soil protein has been made by other workers, it might be inferred that this amino acid was not found or detected. It is possible that the heterocyclic nitrogen of tryptophan may be the source of part of the humin nitrogen.

The amino acid composition of soil material from a quantitative standpoint is yet to be worked out. Although aspartic acid was successfully determined by quantitative isolation, such techniques are probably not applicable to other amino acids. Straight chemical methods such as were used by Kivekäs (2) in determining individual amino acids or groups of amino acids of a water-soluble nitrogen fraction of soil have the disadvantage that they may lack sufficient specificity in the presence of large quantities of substances of unknown constitution. The presence of so much extraneous matter in the soil hydrolyzates makes application of any of the newer techniques such as the microbiological method, isotope dilution method, solubility method, and partition chromatography extremely difficult without an initial separation of the bulk of the amino acids from the rest of the hydrolyzed materials. The microbiological methods might be successfully applied to the crude amino acid fractions isolated for the determination of leucine, isoleucine, and valine.

## SUMMARY

The results of some studies on the amino acids of soil protein in a muck soil from Geneva, New York, are reported. Aspartic acid isolated as the copper salt accounted for 6 to 7 per cent of the total amino nitrogen. Glutamic acid could not be isolated but was determined indirectly by conversion to pyrrolidone-carboxylic acid. Glutamic and hydroxy glutamic acid constituted about 5 per cent of the total amino nitrogen. Hydroxy amino acids as determined by the periodate method accounted for 18 per cent of the total amino nitrogen.

Leucine, isoleucine, and valine were isolated by fractionation of the copper salts and separately identified. The amino acid fractions from which they were isolated accounted for 42.5 per cent of the monoamino-monocarboxylic acid fraction and 31.9 per cent of the total amino nitrogen of the muck hydrolyzate.

Amino acids isolated do not indicate unusual characteristics of the proteins or protein fragments in the muck.

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# BOOKS

*De Betekenis van Borium voor de Plant.* By J. J. Lehr. L. E. Bosch & Zoon, Utrecht, 1940. Pp. 193, figs. 7.

This is a doctoral thesis concerning the amount of boron in the soil, the forms in which it is present, and the means by which it is kept in circulation. Deficiencies are shown to be most widespread in sandy soils, which contain their boron largely in the form of tourmaline. The most available portion of the boron is that fixed in the soil organic matter. Three points are made with reference to the increasing frequency of boron deficiency; namely, use of organic manures is declining, the intensiveness of agriculture is greater, and use of purified and synthetic fertilizer materials is increasing. A list of 73 references is appended.

*Bioelectric Fields and Growth.* By E. J. Lund and collaborators. University of Texas Press, Austin, 1947. Pp. 391, figs. 74. Price $6.

The purpose of this book is to present the findings of the author and his associates on maintained bioelectric fields in polar cells and tissues. Section I has to do with the measurement of polarity in single cells and includes a description of the apparatus. Section II deals with the effects of gravity on the electric correlation field in coleoptiles, also with a description of the apparatus. Section III is concerned with a study of spontaneous variations in the electric field potentials in roots, and the apparatus required. Section IV discusses polar bioelectric fields and polar growth under conditions of applied electric fields. Section V describes the use of the iodine coulometer in the measurement of bioelectric energy. Section VI is a discussion of the results as a whole and their significance. Section VII gives 180 references to the literature cited and, in addition, a bibliography of 1406 references on continuous bioelectric currents and bioelectric fields in animals and plants.

*Radioactive Tracers in Biology.* By Martin D. Kamen. Academic Press Inc., New York, 1947. Pp. 281, figs. 38. Price $5.80.

This book is of immediate interest to all those who contemplate undertaking experiments with radioactive isotopes in connection with the study of the functions of these elements in plants and animals. The book undertakes to review the concepts in nuclear physics, an understanding of which is essential to an intelligent application of tracer methods; to present a critical survey of tracer methods now in use; and to indicate the potentialities and limitations of these methods. Radioactive hydrogen, carbon, phosphorus, sulfur, sodium, potassium, calcium, and strontium are given special consideration. Two other chapters are devoted to the halogens and to another group of elements, including manganese, iron, cobalt, copper, zinc, arsenic, silver, gold, and mercury. The last chapter deals with visualization techniques and medical applications. References are given to the publications of some 650 workers in this field.

<div align="right">The Editors.</div>

## SOIL CONSERVATION AND GOOD LAND USE

Organized effort in soil conservation and good land use, under the general direction of Dr. Hugh Hammond Bennett, Chief of the Soil Conservation Service of the United States Department of Agriculture, has been under way long enough to permit of the crystallization of fairly definite concepts as to the nature of the problems involved and the most promising means of procedure in their solution.

It seemed desirable, therefore, that an effort be made to obtain an over-all picture of the problems and processes in this field of endeavor, as viewed by Dr. Bennett and by those who are most intimately associated with him in field work. Accordingly, he and the seven regional conservators were asked to put down on paper the points about soil conservation and land use that impress them most. Each conservator was also asked to select one illustration for his region that, when considered in relation to all the others, would best serve as a pictorial aid to the presentation as a whole.

It is believed that this method of approach will aid in stimulating better think- ing along these lines on the part of all specialists, who, it is hoped, will take time to study what these field scientists have to say. If this is done, it should make for more rapid progress in getting the needed program under way, and in de- veloping it on a permanent basis. It is with considerable pleasure, therefore, that we present to our readers this special number of SOIL SCIENCE, dedicated to the cause of soil conservation and good land use.

<div align="right">FIRMAN E. BEAR</div>

PLATE 1. HUGH HAMMOND BENNETT

# HUGH HAMMOND BENNETT

Serious science and popular appeal, in nice balance, have marked the careers of three great men of modern America: Gifford Pinchot, of forestry fame; Harvey W. Wiley, fighter for pure foods and drugs; and Hugh Hammond Bennett, man of soil. Only the man of soil is widely known by farmers and city dwellers alike throughout the civilized world. His pioneering work in soil conservation promises to determine in large measure how well mankind will eat tomorrow.

It is because of Dr. Bennett's courage and insistence that we have a Soil Conservation Service today. He called upon his courage only after years of scientific investigations of soil wastage and after additional years in arriving at effective techniques for erosion control. He needed science. He needed courage. And he needed tenacity. The walls of ignorance, indifference, and prejudice were high. Within those walls dwelt not only a complacent public but also a surprisingly large number of fellow soil scientists. His task embraced a score of years of research, making reports, traveling, speaking, using soil auger and pack mule, writing books and articles—anything to carry his case to the people.

Bennett got his start on a farm in Anson County, N. C., where his father told him that a terrace was for "keeping the good soil from washing away." His interest sharpened, young Hugh went on to Chapel Hill, where he found no teacher able to tell him what he wanted to know. In the U. S. Bureau of Soils, after graduation, he found little understanding but many useful assignments.

As a soil surveyor, Bennett visited virtually every county in the United States. Special missions took him to the Canal Zone, to look into agricultural possibilities at the request of Colonel Goethals; to Alaska, to explore farming opportunities along a proposed railroad, and again as a member of the Chugach National Forest Commission. He was in the Army Engineer Corps in the First World War and came back to take a jungle assignment on the Guatemala-Honduras Boundary Commission. A few years later found Bennett in South America as the soils member of a commission looking into rubber production. In the middle '20's he made his historic reconnaissance of the soils of Cuba, which revolutionized sugar production in the island and for which he recently was awarded a gold medal, the Cuban Order of Merit. More recently, he answered calls to help Venezuela and the Union of South Africa with their erosion problems.

In 1933 he was made chief of the new Soil Erosion Service set up in the Department of Interior, which was to move over to the Department of Agriculture as the Soil Conservation Service in 1935. Scientists and laymen alike are generally familiar with the growth of the soil conservation movement under his leadership.

Bibliographies list more than a hundred technical and popular books and articles under his name. He is past president of the Association of American Geographers, chairman of the Pan American Soil Conservation Commission, a Fellow of the American Association for the Advancement of Science, a Fellow of the American Geographical Society, Founder of the Soil Conservation Society of America, and member of numerous other scientific societies.

WELLINGTON BRINK

# DEVELOPMENT OF OUR NATIONAL PROGRAM
## OF SOIL CONSERVATION

### HUGH H. BENNETT[1]

Sometime in the dim past, under the protective cover of vegetation, true soil began to form over much of the earth's surface. For undeterminable time this soil has been extensively used throughout the world for agricultural purposes. Much of it has been used up—wasted, removed by water or wind. Though many protected areas still persist, erosion from the beginning has slowly but continuously been removing material from the surface of the soil. Under the shield of vegetation, the rate of removal often has been so slow as to be unnoticeable, scarcely measurable. Soil building from beneath has kept pace with soil removal from the surface. This exceedingly slow process of soil removal is called *normal* or *natural erosion*.

Thus a balanced or fixed depth of topsoil—the humus-charged soil layer—was maintained over the virgin uplands wherever conditions favored the continuing growth of dense vegetation. The depth of this surface layer averaged about 9 inches throughout our uplands, according to 389 samples of virgin soil collected throughout the United States by the Bureau of Soils.

Why this layer of topsoil did not extend to a much greater average depth, in view of the long time involved in its development, is not clear. It may have been the result of a shielding-off or buffer effect against soil-forming agencies, due to the depth of the topsoil layer itself. Activities of certain soil-building microscopic organisms, for example, may not be so effective beyond a limited distance (depth) from the air.

## ACCELERATED EROSION

Where the land surface is bared of protective vegetation, as it must be for cultivation, the soil is fully exposed to the direct abrasive action of the elements. Thus stripped of the cover that normally holds the soil against the transporting action of wind and water, soil material is frequently moved many times faster— sometimes several thousand times faster—than under normal conditions. This accelerated removal of soil is known as *soil erosion* or *accelerated erosion*. Unless steps are taken to check its progress, it becomes the most effective agency of land impoverishment.

## INTEREST IN EROSION SLOW TO DEVELOP

As a nation, we did not concern ourselves until recently about the costliness of accelerated erosion in any of its diversified effects. We did little to prevent or control the wasteful process, except spottily and for the most part ineffectively.

A few of our early American farmers recognized the destructiveness of soil erosion and undertook to control it. In Virginia, Washington, Jefferson, and

[1] Chief, Soil Conservation Service.

Madison fought erosion with various practical measures, such as crop rotations, application of muck to affected areas, and contouring.

Despite the warnings and practical examples of prevention and control on the part of these early American planters, few farmers adopted soil conservation practices. In a letter to Jared Eliot of Killingsworth, Connecticut, with reference to his recommendations for building up poor land with crop rotations, including clover, Benjamin Franklin said, in 1749 (11, pp. 223–224):

> Perused your two Essays on Field Husbandry, and think the public may be much benefited by them; but, if the farmers in your neighborhood are as unwilling to leave the beaten road of their ancestors as they are near me, it will be difficult to persuade them to attempt any improvement.

In order to slow runoff and the erosion caused by it, a number of plantation operators in Georgia and the Carolinas carried on "hillside ditching"—the forerunner of our modern field terracing—at least as early as 1830.

After the United States Department of Agriculture published, in 1917, C. E. Ramser's bulletin on farm terracing as practiced in the Southeast (18), some of the agricultural colleges put out bulletins on field terracing and dam construction for gully control. Some terrace-building "demonstrations" were carried out here and there. These aroused temporary local interest but usually accomplished little.

Aside from a few geologists, not many of our earlier scientists appear to have been interested in accelerated erosion. Just why there was so little scientific interest in such an astoundingly wasteful and spectacular process is difficult to understand. Greater concern might have served to avoid the costly delay of a hundred years or more in getting a national program of soil conservation under' way. No attempt was made even to carry out simple tests on different kinds of land to determine the rates of erosion or the proper grades for field terraces. This latter important determination was delayed until the soil erosion experiment stations were set up in the early 1930's, a hundred years after terracing began to be used to check erosion.

We were the victims of habit. Our forefathers undoubtedly felt that the fertile lands of America were limitless and inexhaustible. We accepted this view without question, although for generations, following every heavy rain, we had seen runoff spectacularly colored with suspended soil material. These flood waters were as red, as yellow, or as black as the fields whence they came. Why it was not clearly understood and publicized—at least by the more observant—that this coloring material in flood waters was soil washed out of our fields and pastures, I have never been able to understand.

### FEW PROVED PRACTICES AVAILABLE TO EARLY CONSERVATIONISTS

It is of little importance now, however, to concern ourselves with the causes of our past lack of knowledge, because a great many Americans finally have come · to realize the significance of the erosion problem and the necessity for meeting it without delay.

Now that we finally have under way an effective national program of soil conservation well supported by research, some of the more important steps that led to it and to our aroused national consciousness of the need for it may be of interest. Out of the records and my own recollections these are given below.

## DISCOVERY OF SHEET EROSION

My first understanding and genuine interest in the subject of soil erosion was when W. E. McLendon of Bishopville, South Carolina, and I were making a soil survey of Louisa County, Virginia (1), in 1905. Our chief, head of the old Bureau of Soils, had instructed us to look carefully into the reason behind the reputation of the region for the poverty of its farmland.

This investigation proved stimulating, something outside daily routine. We found considerable naturally poor land—soil formed through the decomposition of talcose schist—but we found also many sloping areas of cultivated or formerly cultivated land which had been made poor by erosion. In woodlands that had never been plowed, there was always deep loamy soil. This was rich in humus and so mellow at all times you could dig into it with bare hands. In many adjacent fields, however, there was stiff clay—subsoil—at the surface. Usually this hardened almost to the condition of rock with every dry spell. Under cultivation, a profound change had come about: With every heavy rain, the mellow topsoil had been stripped from entire fields at a time in a thin layer (or sheet) as water flowed off the fields into the streams muddied with suspended soil.

We realized, when we came to understand this continuing process of soil removal, that we had learned the real meaning of sheet erosion, which today is considered the most widespread and costly form of the erosion process.

This fundamental discovery started me on a long journey, studying the erosion process and what it had done to the land over the United States and other countries. But it failed to arouse much interest in Washington. I have suspected that it did not fit in with certain theories about soil fertility that were held in some quarters at about that time (21). At any rate, not much about the subject found its way into the published report on the Louisa survey (1).

## FIRST BROAD-SCALE MEASUREMENT OF THE EFFECTS OF EROSION

Following this experience in the Virginia Piedmont, my next most revealing find was in Fairfield County, South Carolina, where a soil survey was made in 1910-11 (8). This survey showed that of the 483,000 acres in the county, 28 per cent had been so damaged by erosion that the land had no further practical value for immediate cultivation. In addition, most of the topsoil had been stripped from 16 per cent of the land. Since that time, the damaged area has extended even further. Some of the roads we drove over in 1911 with horse and buggy have been completely abandoned because of erosion.

The rural population of Fairfield County at that time was 29,442 (census 1910); the corresponding population in 1940 was 13,462 (census 1940). More than half the farm people had quit the farm! That is one of the deadly things un-

controlled soil erosion does: It forces people off the land by impoverishment or ruin of the soil.

I thought, then, that when the report giving those dismal details of land wastage in Fairfield County was published it would arouse considerable interest. To my astonishment, it didn't even ripple the placid surface of our national complacency with respect to the welfare of the land. People just were not interested at that time.

### PUBLIC INTEREST SLOW TO DEVELOP

Later, I came to understand something of the difficulties of developing national interest in the welfare of the land. Findings more or less like those in Fairfield County were reported from other parts of the country—from Stewart County, Georgia (16) and Lauderdale County, Mississippi (2). But nothing happened. There was neither interest nor comment, just pure indifference—inheritance from those days when our forefathers felt we could never use up our supposedly limitless supply of "indestructible" land! Some well-meaning soil students of the time became so interested in complex fertility studies that they overlooked the terrific rate at which good farmland was being wasted by erosion—never tied it into its relation to the productivity of our agricultural land and our national economy. Some soil specialists thought the land was completely safe, and said, in 1909: "The soil is the one indestructible, immutable asset that the nation possesses. It is the one resource that cannot be exhausted; that cannot be used up" (20).

When I read that unqualified assertion, I learned that it is possible to put much misinformation into two short sentences. The unfortunate truth is: Soil is subject to such waste and violent change by erosion, under hard usage, that, as a nation, we can get along only if from now on we take scrupulously good care of our every remaining acre. Too many farms and too many localities already have come to agricultural grief to permit any further fruitless and costly theorizing, offering of panaceas and short-cuts for soil conservation, and assertions without supporting evidence that "we can get the job done better."

In addition to information on the effects of erosion given in some of the older soil survey reports, the Bureau of Soils published three interesting papers that dealt mainly with the effect of erosion—two with water erosion (10, 17), the third with wind erosion (12). Shaler in 1890, had pointed to the seriousness of the problem and offered (19) some general suggestions as to what needed to be done. In 1908 Chamberlin also gave some pertinent suggestions on soil conservation, especially in his recommendation that farmers should strive to trap as much of the rainfall as possible in the body of the soil (9):

. . . the highest crop values will usually be secured when the soil is made to absorb as much of the rainfall and snowfall as practicable. In securing this maximum absorption . . . the runoff, and . . . the surface wash, will be reduced to a minimum. It has already been seen that the wash of even this inevitable minimum is likely to be still too great to keep the proper slow pace with soil-generation, when the surface has much slope. . . . The practical problem then lies almost wholly in retaining and passing into the soil the maximum of

precipitation. Obviously, this gives the minimum of wash to foul the streams, to spread over the bottom lands, to choke the reservoirs, to waste the water-power, and to bar up the navigable rivers. The solution of the problem for the tiller of the soil essentially solves the whole train of problems running from farm to river and from crop-production to navigation.

In a paper presented before the Third Forestry Congress at Atlanta, Georgia, July 1921 (3), the writer presented a plan for improvement in the use of land according to adaptability and an appraisal of the land-use situation in the South, and pointed out the significance of the erosion problem and the necessity for taking care of it without delay.

### SPREAD OF INFORMATION

During the latter part of the 1920's, a special educational effort was made in the Department of Agriculture to increase interest in the erosion problem. Among other things, Circular 33, *Soil Erosion a National Menace*, was published (5) by the Department of Agriculture. This publication gave the first comprehensive appraisal of the erosion problem in the United States. As a result, the press began to take notice of our estimates and warnings. This helped greatly to bring the problem before the public in true perspective.

### EROSION RESEARCH BEGINS

An appropriation was made through the Buchanan Amendment to the Agricultural Appropriations Bill for 1930, providing federal funds to set up regional erosion stations for measuring the rates of soil and water losses, for making surveys to determine the extent of damage by erosion and location of the principal areas affected, and for working out methods of control (14).

It was not long before overwhelmingly convincing information as to the seriousness of erosion losses was acquired. For example, at the 10 stations eventually established on a variety of farmland throughout the country, more than a hundred thousand quantitative measurements were quickly made of soil and water losses under different conditions of land use. Thus, in rapid order, estimates were replaced with facts.

### NATIONAL CONSCIOUSNESS OF THE EROSION PROBLEM

Through these efforts, a national consciousness of the extent and seriousness of erosion was developed. That alone is worth a very great deal. Not all the facts have as yet been absorbed into public understanding, but there has been enough public thinking about the problem to give encouragement to those of us engaged in the work. For example, banks, railroads, newspapers, civic organizations, soil conservation districts, manufacturing establishments, schools, churches, and individuals are putting out an enormous amount of effective educational information.

Another encouraging thing is that people are beginning to understand something about the real source of food, even though too many still fail to understand that the bulk of our food comes not from the corner grocery, but from productive land, or fail to think, seriously about the matter.

## TOPSOIL BETTER THAN SUBSOIL

Until about 20 years ago the word *topsoil* was seldom heard. And only a few—soil specialists, road builders, and excavators of earth—ever made any very meaningful use of the word *subsoil*. Expressions like *normal erosion* and *accelerated erosion* had not found their way into our dictionaries and agricultural treatises.

Even now, too little attention is devoted to the part good productive land plays in the provision of a healthful, nutritious diet. When the topsoil is allowed to wash off the land, that action completely and wastefully disposes of the whole surface soil layer and all it contains—all that nature and man put into it, including elements of nutrition, both major and minor, and the microscopic organisms that help make land productive by assisting with the conversion of unavailable soil constituents into available plant nutrients. We need to know a great deal more about the relation of eroded land to nutrition. We should understand that what is commonly left for the farmer to till is unprocessed, stubborn subsoil, which usually is less absorbent of rainfall than was the topsoil, is more difficult to plow, and is much more deficient in all available plant nutrients.

Subsoil can be improved, of course, but lost topsoil, which is the most productive part of natural soil, cannot be restored within measurable time. And it cannot be brought back from the floor of the ocean. It cannot be mined from the depths of the earth or made by pulverizing rock. It cannot be grown; it cannot be bought from foreign countries for stockpiling.

Subsoil can be improved with good cultural treatment, including especially the growing of grasses and legumes and the addition of organic manures and mineral nutrients. But even with such beneficial treatment, some particularly unfavorable subsoils do not produce favorably. Generally, subsoil is less productive than the corresponding topsoil, regardless of treatment. For example, the subsoil of Cecil sandy clay loam in south-central North Carolina produced, without fertilization, 290 pounds of seed cotton per acre, compared with 950 pounds under the same treatment by the corresponding topsoil immediately alongside (3-year average). With the same fertilization (green manure and 400 pounds per acre each year of a 4–8–4 fertilizer), the corresponding topsoil and subsoil produced the same years an average of 1,123 and 759 pounds of seed cotton, respectively. Here the ratio of productivity as between untreated subsoil and topsoil was 1:3.2; with fertilization the productivity ratio was reduced to 1:1.5.

Corresponding topsoil and subsoil of a quite different soil type—Muskingum silt loam, in eastern Ohio—produced without fertilization 33.5 and 0.8 bushels of corn per acre, respectively, as an average of 4 years (6, pp. 217–218). Here the productivity ratio—for corn—as between subsoil and topsoil was 1:42.

In both soil types the varieties grown on the corresponding plots were the same and the cultural treatments were identical. Also, the corresponding subsoil and topsoil were essentially identical (as shown by total analysis) in chemical composition except that in both soil types the subsoil contained less organic matter and nitrogen.

It appears that the difference in productivity in both of these soil types is due chiefly to the much lower state of availability of plant nutrients in the subsoil. For this reason and others, soil erosion may be the principal cause of malnutrition—and famine.

### ORIGIN OF THE COORDINATED METHOD OF SOIL CONSERVATION

The present national soil conservation program began on September 19, 1933 (before the great duststorm of May 13, 1934, not after, as so many writers have mistakenly said), as an action program under the Soil Conservation Service (known as the *Soil Erosion Service* during the first 21 months of its life). The real beginning, as I see it, however, was in 1905 with the discovery of sheet erosion in Louisa County, Virginia, referred to previously.

Some of the major events influencing the thinking that led up to the action program in 1933 have been briefly outlined.[2]

When, early in 1933, a proposal to start a nation-wide terracing program with federal relief funds was being considered in the Department of Agriculture I proposed the substitution of a complete program of soil conservation for the terracing program. My contention was that a program which would emphasize the use of but a single measure to combat a process that varied widely across the country with the climate, type of agriculture, soil, slope, and past and potential erosion would be incomplete. Some of us had acquainted ourselves with the downfall of millions of acres of terraced land in the southern Piedmont and upper Coastal Plain regions of the Southeast, where only terracing had been employed as the control agency. Fortunately, the severe losses of soil from the unprotected strips of land lying between the terraces had been measured at the erosion stations and the findings were available to support the belief that erosion could never be controlled with a single-practice method.

The complete plan of protecting land according to its needs and capability was adopted. Quickly thereafter we moved into the Soil Erosion Service, which was set up in the Department of the Interior.

There was no delay, no waiting on formalities. As soon as it was known that there was to be a nation-wide soil conservation program, planning for action got under way. As soon as appointment of a small group of experienced land specialists—mostly from among my former associates in land survey and soil erosion research work—was effected, these men were sent to the field to look for suitable sites for setting up watershed units for carrying on demonstration soil

[2] Among those who took the most active part in the research work begun with funds provided for in the Buchanan Amendment to the Agricultural Appropriations Bill in 1928 were: S. W. Phillips, R. E. Uhland, H. V. Geib, R. H. Davis, J. M. Snyder, W. A. Rockie, G. W. Musgrave, B. H. Hendrickson, O. E. Hays, and the writer—from the old Bureau of Soils; L. A. Jones, C. E. Ramser, R. A. Norton, P. C. McGrew, R. R. Drake, F. O. Bartel H. O. Hill, and G. E. Ryerson—from the old Bureau of Agricultural Engineering; M. F. Miller and F. L. Duley of the Missouri College of Agriculture; and A. B. Connor, W. T. Carter, and R. H. Dickson of the Texas Agricultural Experiment Station.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION REGIONS
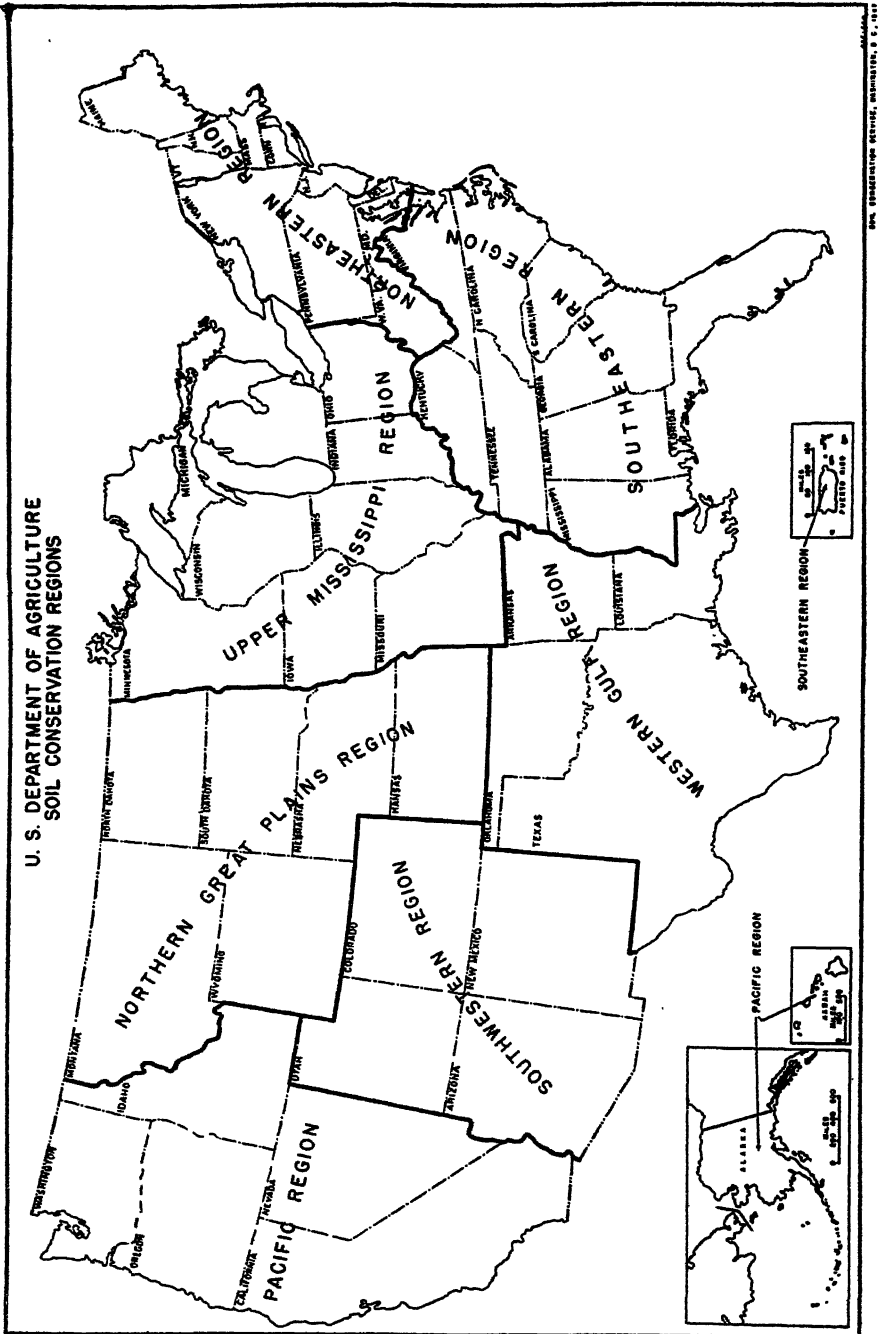
PLATE 2. SOIL CONSERVATION REGIONS OF THE UNITED STATES

conservation work.[3] Various sites were examined before final selection was made. All of them had the approval of representatives of the state colleges of agriculture. Moreover, specialists from the state agricultural experiment stations were asked to help plan the work.

Farmers liked the work from the start and wanted more of it. Soon, the $5,000,000 of relief funds used to start the work was increased, first to $10,000,000 and then to $15,000,000, by those in charge of relief funds.

The original intention was to establish enough demonstration areas so that farmers in the most seriously eroding parts of the country would not have to go more than about 50 miles to see and study examples of the soil conservation work. Soon, however, we began to get out of demonstration work into a strictly action program based on a completely new development in American agriculture. This was the soil conservation district method of operation, under which soil conservation was put under the general direction of farmers themselves—in soil conservation districts.

### DEVELOPMENT OF THE SOIL CONSERVATION DISTRICT IDEA

The conservation district idea developed out of a combination of needs, events, and thinking that took place during the life of the Soil Erosion Service. The needs had to do with a type of organization that would put in the hands of farmers themselves more of the responsibility for getting the job of soil and water conservation promptly and effectively done.

In our field experience with soil conservation work under the demonstration method, we were constantly finding scattered areas of land so severely damaged by gullying as to constitute troublesome problem areas that could not easily be handled on a demonstration basis. Frequently these areas, owned by several farmers, were not readily amenable to effective treatment by individuals. This situation started serious thinking on the part of various members of the service staff as to how such land could best be handled—through what type of organization. What came out of it was a sharpening of the conception that some kind of organization should be developed that would help solve problems of this nature.

When the Soil Erosion Service was transferred from the Interior Department (on March 25, 1935, by order of the Administrator of Public Works, with the approval of the President), various committees composed of technical men in the Department of Agriculture and of the staff of the newly transferred organization were set up to work out procedures for fitting the service into the working organization of the department. One recommendation was that the service should,

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[3] Some of the first areas studied were watersheds and community areas such as: The lower Banister River in south-central Virginia; South Tyger River in southern South Carolina; Brown Creek, in south-central North Carolina; the Dadeville community, in east-central Alabama; the Lindale community in east Texas; Tarkio River and Big Creek watersheds in Missouri and adjacent Iowa; South Palouse River watershed in Washington; several small watersheds in the California-Nevada region; Coon Creek, Wisconsin; middle, Muskingum watershed, Ohio; the middle Susquehanna River area in Pennsylvania; Athens, Georgia, locality; Meridian area, Mississippi; Conway area, Arkansas; Minden area, Louisiana; and north-central area, Kansas.

within a year, carry on its work by furnishing technical assistance to soil conservation districts. Following approval by the Secretary of Agriculture, work began on the development of a model or suggested act for creating soil conservation districts by the states. On February 26, 1937, the President sent printed copies of this suggested act (*A Standard State Soil Conservation Districts Law*) to the governors of the 48 states, recommending the adoption of some such act by the several state legislatures in order to speed up soil conservation work by bringing the farmers more aggressively into action. The recommendation was carried out, and the results have been highly gratifying in every respect.

As of July 1, 1947, 1,865 soil conservation districts were established, and 24 other districts were being assisted by the Soil Conservation Service, in 48 states and Puerto Rico. These districts contain an approximate total area of 1,002,968,000 acres. Five states and Puerto Rico are completely covered. The 1,872 conservation districts in continental United States contain about 653,581,000 acres of "land in farms" and ranches. More than 4,400,000 farms are in these districts. The 17 Puerto Rico districts contain an additional 55,500 farms. With assistance from the Soil Conservation Service, and other public and private agencies, these districts are helping land owners and operators to plan, apply, and maintain conservation on their farms and ranches.

## FARM PLANNING

In order to carry out a completely coordinated soil and water conservation program, properly adjusted to the land, farm by farm, on a nation-wide basis, a great deal of basic information is required. There are hundreds of different soils occupying varied slopes, subject to different intensities of rainfall and snowfall, and adapted to varied crops and cropping practices. From place to place, these differing conditions, together with the different uses made of the land, result in varying susceptibilities to erosion and losses of valuable rainfall as runoff.

Since, as a general rule, no two parcels of land are identical, each field—even each important part of a field—requires its own particular set of conservation practices, one to support another.

Effective soil conservation, according to the basic, guiding principles of the service, is to treat land in a way that will keep it permanently productive while in use. This means, as already indicated, the treatment of every important parcel of land on every farm of the nation with those adaptable measures needed to safeguard all the land permanently and put it all into productive use. This kind of soil conservation not only fits the needs of the land, but it also fits the facilities of the farmer, the requirements of his livestock and poultry, and his preferences as to type of farming.

This is the only kind of conservation that has any chance for permanency. And permanent conservation is the only kind that will keep the United States a permanently vigorous nation. In other words, it is a thoroughly integrated, complete type of conservation—the kind that provides, scientifically, economically, and rewardingly, a balanced, a sufficient agriculture. And it was

originated, developed, and first applied to the land by the Soil Conservation Service.

The soil conservationist has at his command many different types of control measures for handling different types of problems. Unfortunately, however, effective conservation practices have not been developed for all the numerous problems and combinations of problems. It is necessary, therefore, to seek constantly for cheaper, sounder, and more efficient ways for conserving our soil and water resources through an effective supporting program of research.

### NEW METHODS FOR SAFEGUARDING LAND

More and more is being learned about the control of erosion, conservation of rainfall, and better utilization of land in general—through both practical farm experience and research. Long strides have been made in this direction recently, and other important possibilities seem close at hand.

For example, the perennial lespedezas and kudzu have wrought profound changes in the use of much severely eroded land in the Southern States. Lands which a little while ago were considered too poor, too steep, or too erodible to be farmed—even some areas so gullied they could not be plowed at all—are now providing excellent grazing with these valuable crops. And these crops are holding and improving the soil, retarding runoff, reducing the effects of silting, and generally raising farm income by making it possible to give a more important place to livestock.

Throughout the country, the technicians and research specialists of the Soil Conservation Service have been striving to develop as rapidly as possible new field methods and new machines adaptable for use in the control of erosion and in caring for the production needs of each varying locality. Steadily, all this work is taking the form of a new agriculture in our country, an agriculture based primarily on soil conservation farming methods. And to date our progress with effective soil conservation work is pacing the rest of the world.

In making the physical analysis to determine productivity and needs, field men of the service carefully note, on the ground, the exact lay of the land, the quality of the soil, the degree of erosion damage, and the prevailing erosion hazards on every acre of every field, woodlot, and pasture. As accurately as possible, these conservation technicians determine which lands can be cultivated under good farm practices without excessive loss of soil and runoff of rainfall; which lands need the protection afforded by special crop arrangements, special tillage practices, or structural installations; and which ones require a permanent cover of trees, grass, or other protective vegetation.

The next step in soil conservation is to work out with the farmer a farm plan or blueprint for practical operation, based on the ground information acquired. This the technician does, not indoors around a table, but out in fields, pastures, woodlots, gullies, and abandoned and idle areas, working along with the farmer himself. (This system was developed by the Soil Conservation Service, and it is the only agency that has ever used it.)

In some cases, this new arrangement may not entirely fit the farmer's pocket-

book. It may call for more hay crops than he actually needs or can sell and not enough potatoes or corn; it may involve other changes that he cannot afford to make. If so, it is not a good arrangment in a practical sense, and it must be adjusted, if possible, to meet family needs and market opportunities. Purely from the conservation standpoint, however, the farm arrangement based on physical land analysis is ideal. The closer the farmer can approach it and still make a good living, the more stable and productive his land will be, and the surer his income, in the long run.

## APPLICATION OF THE FARM PLAN

Drawing up a satisfactory land-use and land-protection farm blueprint is only half the job. The other half involves the actual application of the plan to the land. Steeper, unproductive croplands, for example, may be earmarked for a permanent cover of grass or trees; farm forests may be planned where grass is not paying or is failing to hold the soil; gullied areas may be turned into grass-covered waterways, farm sanctuaries for animals and birds, or valuable pastures of kudzu. Croplands generally should be farmed in rotation, usually on the level, and sometimes in strips. On the more erodible slopes, terraces are frequently needed for added protection. Pastures need to be limed, fertilized, cleared of weeds and brush, and grazed with caution to improve the growth of grass. Woodlands generally need to be fenced to keep out livestock; always they need to be protected from fire and managed according to scientific principles of forestry. These are only a few of the dozens of erosion-control practices that may be called into use.

The end-product of a properly carried out job of soil conservation is a new arrangement of fields, pastures, meadows, woods, water disposal outlets, and wildlife plantings that safeguards the soil and fits the land as nature made it—and as man upset it. This constitutes an adjustment in land use most nearly meeting the requirements of the physical environment. Together with the adaptable conservation practices and structures, it makes up the complete farm plan for soil and water conservation. Under such a plan, soil conservation is not just an incidental bit of the mechanics of farming: it becomes part and parcel of the whole business of making a living from the land, and is the only way by which we may have permanently productive land for a permanent agriculture.

## CLASSIFICATION AND MAPPING OF EROSION CONDITIONS

The first detailed erosion surveys ever made in the United States were completed in Kansas, Virginia, West Virginia, and Texas, under the direction of the section of soil erosion investigations, of the former Bureau of Chemistry and Soils. These were briefly described by the writer in 1928 (4). Then, with certain refinements, similar surveys were made of various small areas, including the sites of most of the soil and water conservation experiment stations set up with funds appropriated under the Buchanan Amendment to the Agricultural Appropriations Bill for the fiscal year 1930 (7). These early erosion surveys, for the most part, showed the boundaries of the various types of eroded and uneroded

land within the areas covered, the depth of soil and subsoil (after exposure), losses from the uplands as the result of sheet washing, gullying, and blowing, and the depth of deposits of erosion debris over valley lands and along fences and hedges. A few surveys showed some of the principal changes in vegetation resulting from the effects of erosion.

. These represented a marked advance over the rough indications of excessive erosion a few soil surveyors had included from time to time in their published reports. Though the early references were helpful as educational material for arousing a national consciousness of the costly advances of accelerated erosion in America, they furnished no adequate basis for planning soil and water conservation operations.

The soil surveys that were available when the newly created Soil Erosion Service began field operations early in 1934 proved entirely inadequate for preparation of farm plans needed in executing the complete and coordinated type of soil and water conservation work adopted by the service as the basis for its operations. Soil surveys were helpful mainly in identifying soil types. They failed to meet the requirements of the practical soil and water conservationist because they lacked detail, did not show slope (except for a few which used the topographic base maps of the U. S. Geological Survey), failed to present any classification of erosion effects by types or groups that would suffice for conservation farm planning, gave little or no information as to degree of erosion, and generally showed nothing with respect to land use.

A nation-wide reconnaissance of erosion was carried out by the Soil Erosion Service in 1934 and 1935 and was published by the Soil Conservation Service in 1935. Until this reconnaissance erosion survey was made, there was no source of information in existence showing in any adequate way the general extent and distribution of erosion throughout the United States.

A short time before the establishment of the Soil Erosion Service, Glenn Fuller of the Georgia Agricultural College and the writer had completely revised the previous methods of mapping the effects of soil erosion. The first work was done in the Piedmont section of Georgia, starting on February 9, 1933 (13). The surveys showed not only the physical factors, soil, slope, and degree and kind of erosion, but also the broader types of land use.

Here was the first attempt, so far as is known to the writer, to classify and map erosion conditions in their relation to other physical characteristics of the land in sufficient detail to serve as a basis for adequate farm planning. This information, which should have been available long before, immediately provided a far better understanding of soil erosion and the land than anything we had ever had.

These first surveys proved extremely useful in planning for the application of complete soil conservation operations, both for erosion control and for land-use adjustment. The Soil Erosion Service adopted this type of survey as a basic tool of its action program on the land. Its successor, the Soil Conservation Service, continued to use this survey, with occasional refinements, until the extremely careful type of land analysis and interpretation was developed by the

Soil Conservation Service, through its experience and research, in the form of farm maps showing land capability.

Finally, we are now producing a simple map which generally shows no more than eight land classes. These classes range from land of such favorable quality and condition as to require no special treatment for proper cultivation and adequate protection against erosion (Capability Class I), through land that requires a variety of treatments for efficient and safe cultivation (Class III), to land that should never be cultivated under any circumstances (Class VIII).

This is no more than the barest outline of the new and comprehensive soil conservation survey and land capability analysis which is receiving widespread approval of farmers and soil and water conservationists throughout the country (15).

### ONE HUNDRED YEARS HENCE

Looking ahead to the time when all of the nation's farmlands have been treated with sound, basic soil conservation measures—which I think could and should be done in a much shorter period than 100 years—we shall see that striking changes have taken place across the country. Probably among the most outstanding of these will be those tell-tale landscape characteristics which show that our highly variable land has been treated, acre by acre, with efficient measures of protection that can be applied only through the hands of those who know and love the land and understand its needs, capabilities, and importance to the individual and the nation.

All types of land will be in productive use of some kind. There will be no such areas as we now commonly see in useless hideous gullies, burned-over skeletons of forests, and wildernesses of bramble and scrub. Valuable forests and protective growths of grass, vines, and other useful plants will cover those areas that have been made useless for further cultivation through unwise cropping.

Adjustments in land use will have been carried to the point where the more hazardous kinds of farming operations will be appropriately fitted to soil, slope, and climate. Cultivated crops will be on the flatter lands where the soil is deeper and more productive; the steeper lands of shallower, more erodible soil will be covered with trees, grass, or other protective growths.

Man on the land will have been adjusted to his environment better than ever before. His reward will be easier farming, safer farming, larger yields, increased income, and increased happiness. People will be more neighborly and will have a better perspective on our individual and collective obligation of stewardship toward the land.

There will be:

1. No accelerated erosion of any consequence
2. A steadily improving land resource
3. Minimized siltation and flood hazards
4. Less drouth
5. Elimination of idle land on farms
6. Use of nonagricultural and nonforestry lands for wildlife

7. A balanced and generally diversified type of production based on the use of land according to its inherent capabilities
8. A more balanced farm income in the sense that income will generally be derived from a wider variety of crops, including more livestock on adaptable farms
9. Improved nutritional quality of food and better fiber
10. Many millions of acres of formerly unproductive land in use as a result of drainage and irrigation
11. More and purer water available
12. Increased opportunity and happiness on the farm.

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# SOIL CONSERVATION AND GOOD LAND USE IN THE NORTHEASTERN REGION

AUSTIN L. PATRICK[1]

## DESCRIPTION OF THE REGION

One third of all Americans in these United States live in the twelve states of the Northeastern Region, which stretches northward from West Virginia to Maine. They are packed together in an area that covers only one fifteenth of the nation.

In this great industrial and commercial section, industry often overshadows agriculture. In the steel mills of Pittsburgh, on the loading docks of New York harbor, or in the textile mills of New England, it is easy for people to forget the importance of agriculture. Many city people reflect only that milk is something left by the deliveryman every morning, and a beefsteak is bought at the corner market.

Despite industry's dominant position, however, there are certain compensations for the Northeastern farmer. Usually, he is near a market that will take everything he can raise and pay a relatively high price for it. With only 6.7 per cent of the nation's land area, the twelve Northeastern States take in 12 per cent of the national farm income. Generally speaking, farms in this region have a higher average income per acre than those of any other section of the United States. In 1945, for instance, farmers of famed Lancaster County, Pennsylvania, marketed products worth $50,609,473, or an average of $5,311 for each farm.

Hand in hand with high income go high land values and high taxes. Especially is this true in areas within commuting distance of large cities. Suffolk County, New York, is an outstanding example. In 1945, the farmland and farm buildings of Suffolk County were valued at $54,429,446, an amazing average of $25,833 for each farm. Many of these farms, of course, are actually country estates owned by wealthy New Yorkers. Nevertheless, they highlight a condition that exists in other areas of New York, Massachusetts, Maryland, and Pennsylvania.

Because of their nearness to cities and factories, many Northeastern farmers earn additional income by working away from the farm. Approximately one third of all farm operators work 5 to 6 months each year in mines, factories, mills, or elsewhere in industry And on a third of the farms, crops and livestock are grown not for market, but principally for home use.

Dairying and general farming predominate in the region, but some sections deal in specialty crops. For example, there are the tobacco-growing areas of southern Maryland, the Connecticut Valley, and eastern Pennsylvania. There are the truck farms of New Jersey and Long Island, the vineyards of central New York, and the orchards of northwestern New York, southern New Jersey, and the Great Valley area of West Virginia, Maryland, and Pennsylvania. The majority of

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West Virginia farmers are livestock producers, concentrating mostly on the growing of beef cattle and sheep.

Some of the vegetable farms are giant business enterprises. If you should visit the Seabrook Farms near Bridgeton, New Jersey, you would find 19,000 acres under cultivation. Part of the land is irrigated. Everything is done scientifically, and the Seabrook management believes so strongly in soil conservation that it has a staff of eight men working constantly to find better farming methods. In an average year, this great commercial farm will grow nearly 5,000 *tons* of shelled peas—plus equally large quantities of other vegetables that are canned or quick-frozen right on the farm.

Maine is famed for its potatoes. Last year the state harvested 75 million bushels, the major part grown in Aroostook County. The region as a whole grew 27 per cent of all potatoes produced in the nation. Long Island is nationally known for its ducks, Vermont for its maple syrup, and Chester County, Pennsylvania, for its mushrooms. Sussex County, Delaware, raises one fourth of all broilers served on the nation's dining tables. Milk production per acre of farmland in the Northeast is nearly three times the national average and is exceeded only by some of the Midwestern states. On a similar basis, the region leads all others in egg production.

Except in a few instances, however, the Northeast has not lent itself easily to specialized or single-crop farming. The rolling hills, the many rocky and shallow soils, and the fairly long winters have encouraged thrift and a diversity of farming enterprises.

The summer greenness of the Northeast often deceives the casual observer. Look out the window of a train in July and you will see a lush landscape of grass, shrubs, vines, and trees. Here and there you may find a few gullies, but they're not of dramatic size. Nature seems to have spread her protective green mantle over the land. It is easy to feel complacent about this land.

Actually, the surface appearance is misleading. Sheet erosion has taken serious toll in many places. Over a good part of New England and farther south, in Maryland, Pennsylvania, and West Virginia, one fourth to three fourths of the original topsoil is gone. It was washed down the slopes, a thin layer at a time, as muddied runoff from unprotected areas.

Extending along the Atlantic Coast from the Potomac River to southern Maine is a coastal plain—a belt ranging in width from a few miles in the northern end to more than 100 miles in the southern end. This plain in many places is sandy and poorly drained. In some sections, when proper drainage is installed, the light soils are subject to wind erosion. It was on this coastal plain that the early settlers first hacked down forests and began tilling the soil.

Stretching down through the heart of the region is the Appalachian Chain, with its mountain masses, its plateaus, and its deeply infolded and stream-cut valleys. A maximum of 50 inches of rain and snow falls in the mountains. A minimum of about 30 inches occurs along Lake Ontario in the Finger Lakes region of central New York and in some other sections of the region. Over a large part of the mountain area, snow covers the ground from the middle of December

until the end of February. During the winter, this snow protects grasses, legumes, and grains, but when spring thaws come, there may be floods and serious erosion. This is particularly true if the soil is not tied down by vegetation.

The greater part of West Virginia, western Pennsylvania, and southern New York is in the deeply dissected Allegany Plateau. Extending east and west across northern Pennsylvania and New Jersey is the southern boundary of the glaciated area. The country north of this boundary is largely covered with a thick mantle of mixed glacial materials. The natural drainage here is often poor. South of this boundary, the soils are residual or colluvial and are generally shallower to the underlying rock.[2]

Many farms in New England have been in cultivation for more than 200 years. At first, the English colonists paid little attention to soil depletion. They grew corn, wheat, and tobacco on the virgin land. Then they moved to a new piece of ground. When the territory beyond the Appalachians was opened, farmers who had sapped the fertility from land along the coast poured through the mountain passes, headed westward. Again, they repeated the cycle of clearing and planting.

It was not until after 1800 that any attention was paid to crop rotations, liming, fertilizing, or other soil-improving practices. About 1820, farmers began investing more capital in land improvements, and the first four decades of the nineteenth century saw many beneficial changes in the Northeast. Timothy and clover came into use; green manure crops were turned under. By the time of the Civil War, the agricultural economy of the Northeast had become somewhat more stable. Farmers had to face tremendous western competition, which could undersell them because of cheap land and large-scale farming, but nearness to markets gave them an advantage in supplying cities with vegetables, milk, and fruits.

But do not assume that land deterioration has stopped in the Northeast. Even today, with 142 soil conservation districts covering nearly 78 million acres, or 60 per cent of the Northeastern Region, the job of curbing erosion and getting conservation practices established on the land is only well begun. By January 1, 1947, farmers in districts had applied complete conservation plans on about 2 million acres of the total of 61 million acres of farmland in the region.

### IMPORTANT PROBLEMS AND THEIR SOLUTION

#### *Maladjustments in land use*

In the Northeast, as elsewhere, much of the land is not being used according to its capabilities. Conservation surveys indicate that there are nearly 600,000 acres of cultivated land that is so sloping or so shallow that it is not suitable even for pasture, but should be planted to trees. There is an additional $2\frac{3}{4}$ million acres of pasture land that should be converted to woodland. On the other side of the ledger, however, one finds nearly 2 million acres, now in woodland, that

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[2] For further detail as to topography, see *Soil Conservation* (McGraw-Hill Company, New York).

PLATE 3. THIS HILL FARM IN MONROE COUNTY, WEST VIRGINIA, HAS THE PROTECTION OF DIVERSION TERRACES AND CONTOUR STRIPS. THOUSANDS OF OTHER SLOPING ACRES IN THE NORTHEAST NEED THE PROTECTION OF SOIL CONSERVATION MEASURES

could be used safely for crop production. Adjustments could be made both in developing new crop land and in reforesting or seeding to grass part of the cultivated land. From the standpoint of erosion control, the most immediate need is to shift cultivated lands that are unsuited for crop production to trees or grass.

In West Virginia, for example, almost half of the nearly 9 million acres in the state is too steep or too shallow to cultivate. Yet more than 300,000 acres of this steep land is plowed each year. Another 1,100,000 acres now in pasture is actually best suited for forest use.

Likewise, in Maryland, many hillsides are planted to tobacco year after year. Erosion is severe. Silt is washed onto highways or travels downstream to choke reservoirs, harbors, and streams.

*Intensive use of small farms.* A part of the land abuse in the region arises from the feeling of farmers on small farms that they need to cultivate intensively in order to get an adequate income. In West Virginia, the average farm has only 89 acres. More than half of the farms have less than 70 acres. An economic unit for raising livestock in West Virginia should have not less than 200 acres. The average size of a farm in Maryland is only 102 acres. Again, it is obvious that economic pressure makes many Maryland farmers cultivate land unsuited for growing tilled crops. In fact, some farmers are still clearing land that should remain in trees.

In other sections, particularly near large cities, high land values and high property taxes have resulted in unwise use of much land. Many farmers of the Connecticut Valley shun crop rotations because hay or small grains do not return as much profit as tobacco or truck crops. As a result, much of the light soil has become badly eroded largely because of reduction of soil organic matter.

In New England, not only are farms small, but they are often irregularly shaped, rocky, and enclosed in stone walls. These walls, picturesque though they may be, create many farm management problems and hinder the establishment of needed soil conservation practices, especially contouring.

Probably two thirds of the estimated 7,500 miles of stone walls in Massachusetts should be removed for better field management. In addition, many fields have large glacial boulders that interfere with modern machinery and soil conservation practices. Some of these walls and boulders have been removed at considerable expense, but so far only a fractional part of the job has been completed.

*Effects of farm tenancy.* In the southernmost states of the region, the high rate of farm tenancy leads to land mismanagement. Twenty-three per cent of the farms in Maryland and West Virginia are tenant-operated. Too frequently, both landowner and tenant are interested only in extracting everything they can from the land without putting anything back. The usual owner-tenant contract gives the tenant little incentive to build up the farm through conservation measures.

In New England, the tenancy rate is low, but much good farmland has been bought by city people for building sites or for summer homes. Usually, summer residents make little or no use of the productive areas of their farms. Many

New Hampshire farmers are growing crops on land inferior to other land removed from production by summer residents. In Massachusetts, because of the dense population, much of the best farmland has been taken up for building and home sites.

*"Ribbon farms" of Maine.* Up in the St. John Valley of Maine are narrow fields called "ribbon farms." Once these farms were parts of a large French grant, but, through subdivision among heirs, they are today only 15 to 40 rods wide and often a mile or more long. Similar to farms on the old Spanish land grants of New Mexico, they border a road or a stream on the short side and often extend in length over two or three steep ridges. Clearly, it is difficult to make best use of the land and establish strip cropping, diversions, and other conservation practices with this pattern of land ownership.

*Misuse of orchards and woodland.* The demand for vegetables during the war caused some misuse of land. The western part of the limestone belt of central New York, for instance, was once an important fruit section. Today, the orchards are nearly all gone, and cash crops predominate. There is too much cultivation and too little grass cover for the well-being of the land.

In every state of the region, there is urgent need for better forestry practices on the 20 million acres of farm woodland. Clear cutting of woodlands goes on in spite of definite proof that selective cutting, over a period of years, will yield the owner a greater income. Too many woodlands are still grazed by livestock that destroy seedlings and prevent natural propagation. In addition, livestock compact the soil and hasten the decomposition of leaf litter, thereby accelerating water runoff. In 1945, New York alone pastured livestock on more than 1½ million acres of woodland.

In soil conservation districts, many farmers are now arranging with contractors to harvest timber by selective cutting. Much progress has been made: much remains to be done.

### Soil erosion

As said before, the most serious soil losses in the Northeast result from sheet erosion. On the coastal plains of Maryland, Delaware, and New Jersey erosion has been found on surfaces with slopes of only 1 to 3 per cent. Usually, however, serious erosion in the region is restricted to slopes of 3 per cent or more.

Sheet erosion is hard to see. That's why it is so dangerous. In many sections, there are long, sloping fields where half of the fertile topsoil has washed off in less than 40 years of farming. Yet such fields often show no signs of erosion on first glance.

The critical erosion period in the Northeast is early spring—between the time the first snow melts and the time that summer crops give protection to the land. Whenever possible, farmers are urged to plant winter cover crops. But sometimes, as in the Maine potato country, the cultivated crop comes off the ground so late in the fall that a cover crop cannot be put in. Where vegetative measures of protecting land are inadequate, they should be supplemented by engineering structures.

The destruction of forests and the cultivation of sloping land have combined to produce the greatest amount of erosion in the Northeast. As one example, on approximately 90,000 acres in the northern part of New Castle County, Delaware, from one fourth to three fourths of the original topsoil is gone. Throughout the region similar conditions exist.

The remedy, of course, is a combination of good land use and the application of soil conservation practices. If sloping land is to remain in cultivation, it should have contour strip cropping, terraces, or diversions, or a combination of these things. Otherwise, it should be returned to pasture or woodland.

*Wind erosion in Northeast.* A 450-mile area extending along the Atlantic Coast from Delaware to Massachusetts is subject to wind erosion, although not to the degree that the southern Great Plains area suffered in the middle '30's. The most serious wind erosion in the region occurs on Long Island, where winds sometimes reach a velocity of 85 miles an hour. At Montauk Point, an average of 109 separate winds each year have a velocity greater than 50 miles an hour, according to the Weather Bureau. Velocities of 60 to 80 miles are fairly common.

In Delaware, New Jersey, and Rhode Island—as well as on Long Island— sand blows are always a threat in early spring. Strong, drying winds evaporate the moisture on the surface of the sandy soil, but the subsoil remains frozen. For that reason, water movement is greatly reduced or stopped, and the winds pick up the dry surface soil and whisk it away. Newport County, Rhode Island, suffered serious damage from wind erosion this past winter. In some places, dust columns mounted as high as a quarter of a mile.

Because of high taxes and high land values, these sandy coastal soils are cropped intensively, and farm operators feel they cannot rotate crops. For many years in the past, vast supplies of manure from city stables, plus cover crops, supplied needed organic matter for these farms. In this day of trucks and automobiles, city manure supplies no longer exist. The truck grower and the market gardener using sandy soils are hard put to it to maintain sufficient organic matter to bind and hold soil particles against the erosive action of wind and water.

Windbreaks, winter cover crops, planting crops in rows running at right angle to the prevailing wind, more organic matter in the soil—these are the chief conservation measures to be used in coping with wind erosion.

*Streambank erosion.* Streambank erosion is a serious problem throughout the region except in the tidewater areas. In northern New England, especially in Vermont and New Hampshire, it is an extremely serious problem. This is largely because in these states a high proportion of the fertile, tillable land is bottom land. Even though the actual acreage of bottom land may be relatively small, it is important, since it frequently constitutes the major part of the farm suitable for cropping.

In many localities, streambank erosion also endangers highways and railroads that were built in the valleys beside streams or rivers. Sometimes, too, factories placed near rivers may be affected.

Experience gained in controlling streambank erosion on the lower Winooski River in Vermont, and elsewhere, shows that every foot of the bank presents a

specific problem. No single, over-all practice gives the answer. Vegetative measures on properly sloped banks, supplemented by rip-rap, piling, cribbing, or other engineering aids, are the usual recommendations. If people are to continue earning a living from the land in certain areas, the problem of stream-bank erosion must be solved. The landowner must have public assistance to establish and maintain the costly measures that are needed.

### Water conservation and control

The most serious wastage of water in the Northeast takes place in June, July, and August. During this period, rainfall is irregularly distributed and may come in hard thunderstorms. Moreover, this is the critical period of the growing season—the time when plants need most water for fast growth and mature development.

Contrary to popular opinion, drought is fairly common in the Northeast during the three summer months. Twenty-nine stations of the Weather Bureau kept records on summer rainfall in New York State over a period of 25 years. During only 7 to 12 of those years was there enough summer rainfall for good crop growth.

Under the usual system of farming, where crop rows run up and down the slope and grain crops are planted on slopes, much summer rainfall fails to penetrate the soil but runs off, carrying soil with it. Such soil conservation measures as contour tillage, strip cropping, pasture improvement, and diversion ditches conserve water. They provide temporary storage, slow runoff, and increase infiltration.

Sometimes, lack of water in the summer causes total crop failure. At the very least, it reduces yields and lowers the quality and market value of crops. Recent studies in nutrition also indicate that plants will store up a maximum amount of minerals and vitamins only if they have ample water during the growing season. A water-starved vegetable is not only stunted, it is less healthful.

Water losses also affect city water supplies and industrial plants. Unless water soaks into the ground, the underground water supply is lowered and cities that depend upon artesian wells may suffer. Furthermore, if streams are used for the disposal of industrial wastes or sewage, the pollution problem increases greatly when stream flow is at a low ebb.

*Farm ponds.* On many farms, water is being conserved in ponds. So far, farmers in soil conservation districts of the Northeast have built 1,423 farm ponds. The demand for farm ponds is just beginning. No one knows how many thousands of them will be requested in the next few years. Last year, for instance, West Virginia alone built 530 such ponds.

For the livestock farmer, the pond provides a source of water for his animals throughout the year. For the orchard or vineyard owner, the pond offers water for spraying or irrigation. By using water from ponds, truck farmers grow better vegetables. And if ponds are placed near farm buildings, they are invaluable in the event of fire.

When a pond in the Northeast is fed by surface runoff, the watershed should not exceed about 30 acres of open fields or 60 acres of woodland for each acre

of pond surface. Ponds in the region usually are designed with a depth of 3 to 6 feet, although in New York and New England even greater depths may be needed, particularly if fish are to be produced.

*Irrigation.* Contrary to popular belief, irrigation is not new in the so-called humid Northeast. As early as 1796, Connecticut farmers were irrigating their fields. In 1877, Henry Stewart's *Irrigation for the Farm, Garden, and Orchard* dealt largely with irrigation problems in the Northeast.

Overhead sprinkler systems, of both the permanent and portable types, are being used today by truck farmers and nurserymen. Irrigation pays dividends when per-acre yields are high. Vegetable crops get to market sooner and command a higher price because of improved quality.

When sufficient water is available, sprinkler irrigation is profitable for potato production. Whether or not irrigation will pay for itself on pasture and hayland is a moot point. Experiments now being conducted at the Arnot Station in New York are not far enough along to be conclusive.

The amount of land being irrigated is steadily increasing. When manufacturers design cheaper, more efficient portable systems, there will likely be a marked increase in acreage under irrigation. In general, irrigation farming in the Northeast gives greatest returns where crops are grown intensively on very fertile land during periods of high prices.

*Flood control.* One problem with water is to conserve it for agricultural use. Another is to control it so that floods are less likely to occur.

Flood damages in the Northeast range from only a few hundred dollars on small tributaries to thousands of dollars on some of the larger basins, especially where there are cities or industrial plants along rivers or streams. Each watershed is an individual problem.

Siltation of streams and harbors has been a fairly serious problem in the Northeast since Colonial days. In Maryland, more than a dozen important early settlements along Chesapeake Bay became ghost towns when harbors filled with silt and ships could no longer reach their landings. During the last 100 years, the federal government has spent more than $17,000,000 to remove some 111 million cubic yards of sediment from Baltimore's harbor. In addition, the city of Baltimore has spent several millions.

Sedimentation of reservoirs is not nearly so rapid as it is in the West, but nevertheless the cultivation of sloping, erodible land has hastened the process in the Northeast. For example, Baltimore built a city water reservoir on Jones Falls in 1862. By 1900, the city had spent $83,000 for dredging, and it finally abandoned the reservoir in 1916. A second reservoir, built on Gunpowder Falls in 1881 at a cost of $321,000 was likewise given up in 1912 after 2,200,000 cubic yards of sediment had been dredged.

Meanwhile, Baltimore has built two other reservoirs, which are silting slowly. The rate of siltation is low only because the enormous storage capacity—a total of 41 billion gallons—is developed in a small watershed of 303 square miles. Actually, sediment production is well above the average for the southern Piedmont, a region of notorious soil erosion.

*Drainage.* In the Northeast, there are approximately 4,800,000 acres of poorly

drained land. About 3 million acres of this land have been cleared and are producing row crops or hay, but maximum production will be achieved only through the installation of better drainage systems.

A large part of this wet land lies in a 25- to 100-mile strip along the Atlantic Coast in New Jersey, Delaware, and Maryland. Another large section is along the Great Lakes in Pennsylvania and northern New York. In other parts of the region, drainage is a serious problem, but it is confined to small group projects and individual farms.

At present, only two states—Maryland and Delaware—have active, legally organized drainage enterprises. The failure of other states to undertake large scale community drainage projects is laid to the lack of a workable state drainage code, complex drainage laws, the customs and habits of farmers, and a lack of interest by state leaders.

In the region, approximately 1,290 miles of community outlets have been completed, providing outlet drainage for some 45,000 acres of land. One of the largest of these is the Pocomoke River drainage project on the Eastern Shore of Delaware and Maryland. This project starts about 7 miles north of Snow Hill, Maryland, and continues into Delaware to a point north of the town of Gumboro, a distance of 22 miles. It will provide outlet drainage for 95,280 acres, of which 42,280 acres are now under cultivation. The Pocomoke River has been completely dredged and realigned up to the Delaware line, and work is now going on in Delaware. After the river channel work is finished, it will be necessary to put in several miles of laterals (tax ditches) before individual farms can be drained.

Many Maryland farmers have doubled per-acre production after installing drainage systems. In several instances, bigger crop production has paid for drainage costs in only one year.

Removal of excess water from poorly drained soils on individual farms is a serious problem in every state of the region. Probably one million acres lying within soil conservation districts need better open-ditch drainage. An additional 49,000 acres could be improved by tile drainage. Soil conservation districts have built more than 8 million linear feet of farm drains, benefiting 72,400 acres.

Tile drains are used most commonly in the truck crop areas of New Jersey and New York. They are widely used for drainage of small wet spots.

Three things are essential in an open-ditch drainage system: The outlet, which may be an existing tax ditch, roadside ditch, or any channel with sufficient capacity to handle the water; the header ditch, which is a large V-shaped ditch; and the field drains, which are small V-type ditches laid out in parallel lines from 40 to 100 feet apart. Both header ditches and field drains are built so they can be crossed with farm equipment and plowed out occasionally for maintenance.

On sloping land, drainage diversions are frequently needed. They are built just like ordinary diversions except that they intercept subsurface seepage as well as surface water. These diversions have worked out very well in western New York and western Pennsylvania.

## Special problems

Of the many special land problems in the Northeast, perhaps four are outstanding: soil acidity, stoniness of New England fields, sandiness of coastal areas, and poor management of pastures and woodlands.

*Soil acidity.* Soil conservation surveys indicate that more than 17 million acres of grazing and pasture land in the Northeast are in need of agricultural lime to counteract excessive soil acidity. With the exception of a strip bordering the Great Lakes, most of the farmland has been formed from acid parent materials. Lime is needed on 5 million acres in New York, 3½ million acres in Pennsylvania, and another 3½ million acres in West Virginia. In the Northeast, lime is as necessary for maximum hay or crop production as salt is in our everyday diet.

Thousands of farmers have recognized the need for lime, and many of them are carrying on a strong battle against soil acidity. A few soil conservation districts are buying or manufacturing lime on a cooperative basis. The West Fork Soil Conservation District of West Virginia, for example, built a $30,000 lime plant last year at historic Rich Mountain in Randolph County. Constructed with funds borrowed from the State Conservation Committee, this plant has a capacity of 50 tons, which includes a small return to the State Conservation Committee. Before long, the district supervisors believe, the costs will be pared to around $5 a ton. West Fork supervisors estimate that a million tons of lime are needed as an initial application on the 7,400 farms in the district.

*Stone walls and rocky fields.* Besides having to cope with sour soils, many Northeastern farmers—particularly those in the New England states—have the problem of stony fields. For ten generations, New England farmers have been removing stones from fields. In the old days, it was common practice for the farmer, his sons, and the hired man to pitch in after harvest and "make" an acre or two of land by clearing stones from the field. Most of these stones went into walls, partly because that was one way to get rid of them, partly because enclosures were needed.

Today, soil conservation districts are using bulldozers to remove unnecessary stone walls and large field boulders. Having a place to put the stones often poses a problem. Sometimes, they are loaded on a steel stoneboat capable of carrying a load of 10 to 15 tons and carried away to ravines or swampy areas. Other times, trenches are dug and stones are buried with at least 2 feet of soil on top of them. Many farmers feel it is better to improve their own land by removing stones than to buy comparable improved land some distance away. They already have a certain overhead in buildings and equipment, and, moreover, improved land nearby makes a more efficient unit.

Vermont has as much as 112,000 acres that could be cleared, leveled, and converted to pasture. Rhode Island plans eventually to remove 135 miles of stone walls. In Massachusetts, possibly 4,000 to 5,000 miles of stone walls should come out. Thus, it will be seen that the problem of leveling fields, removing stone walls, and rooting out glacial boulders is a big one that will not be solved overnight.

*Sandy areas.* Whereas some areas are too stony, others are too sandy. In the forested portions of the coastal plain of New Jersey, Delaware, and Maryland, vast sandy areas are yielding very little return to the landowners. An outstanding example is the so-called Pine Barrens of New Jersey, an area of more than a million acres nearly completely forested with a poor stand of scrub oak and pine. Scattered throughout the area are extensive cranberry bogs.

It is doubtful whether any large part of the Pine Barrens will be developed for truck crops and fruits in the immediate future. For one thing, once these lands are cleared and properly drained, they are very vulnerable to wind erosion. To keep these lands in permanent crop production, New Jersey farmers would have to use such conservation practices as windbreaks, contour cultivation, diversions, terraces, fertilizer, cover crops, and lime.

*Pasture and woodland management.* Since dairying is one of the most important enterprises of the Northeast, the development of better stands of grass and legumes for pasture and hay production is a matter of special interest. The cool, humid climate is ideal for grass and legumes; the grass and legumes, in turn, anchor the soil and build up its fertility.

Too many pastures in the Northeast are merely exercise lots for dairy cows. The vegetation is low in nutritional value and inadequate for soil protection. In all of Pennsylvania, for instance, only one county, Chester, is outstanding for its fine pastures.

Soil conservationists and farmers should constantly bear in mind this need for improved pasture land. Conversion of some cropland to grass, proper liming and fertilizing, and reseeding will be needed.

Closely related to the problem of building better pastures is the need for improved woodland management. Because of a shortage of pasture, many woodlands are grazed by livestock. Thousands of acres now in pasture or crops should be reforested. According to soil conservation estimates, nearly 4 million acres need to be planted to trees.

The 20 million acres of farm woods in the twelve Northeastern states represent approximately one third of the nation's commercial woodland in private ownership. Nearly every farm has some woodland in its acreage. These woodlands are a source of fuel, lumber, and posts needed on every farm, and they also furnish products for sale.

Unfortunately, though, the farm woodlot is often treated as the backyard of the farm and gets little attention. Many farm woodlands are run down. They have been burned, overcut, or overgrazed.

## A SUMMING UP

In this brief paper it has been possible merely to sketch in broad strokes the major land use problems of the Northeastern Region. As we have noted, many persons have been lulled into a false sense of security by assuming that erosion has made only minor inroads in a region that is so well adapted to the production of forage crops and trees.

Actually, the shortage of fertile, reasonably level cropland has caused many

farmers to use their land more intensively than they should. Soil erosion has affected nearly all of the sloping land. Over a large part of the region, from one fourth to three fourths of the topsoil has been lost. Nearly one third of the cropland is critically eroded; slightly more than one third is seriously impaired; much of the remainder is slowly deteriorating.

Because of severe competition from other regions where good cropland is more plentiful and mechanized farming is more profitable, Northeastern farmers have turned more and more to the marketing of bulky, perishable products. Milk, poultry, eggs, potatoes, fruits, and vegetables are produced and rushed to urban markets.

Fortunately, even though they are using their land intensively, many Northeastern farmers have come to recognize the need for a complete soil conservation program. Many of them know that their land cannot remain permanently productive unless they tie down the soil and build up its fertility.

But they have a host of vexing problems to overcome—such problems as the clear cutting of woodlands, unproductive pastures, acid soils, sloping and stony fields, poor woodland management, lack of organic matter, streambank erosion, widespread sheet erosion, and inadequate drainage. These problems can be solved only through patient, persistent, and intelligent effort.

# SOIL CONSERVATION AND GOOD LAND USE IN THE SOUTHEASTERN REGION

## T. S. BUIE[1]

### DESCRIPTION OF THE REGION

From the rich limestone valleys of Virginia, Kentucky, and Tennessee to the citrus-fruit groves and truck farms of Florida, probably more different crops are grown than in any comparable area of the United States.

Excepting Florida, there is also a larger area of severely eroded land in this Southeastern Region than in any other distinct region of the United States—notwithstanding the efforts at erosion prevention by such competent farmers as Washington, Jefferson, and Randolph. It can be fairly be said, however, that no region is advancing more rapidly from soil-depleting to soil-conserving types of farming than the Southeast. This is particularly true of the old cotton-growing states—the Carolinas, Georgia, Alabama, and Mississippi.

Puerto Rico and the Virgin Islands are included in the region, but this discussion is limited primarily to the nine states of the Southeast. These occupy two major physiographic regions: the Atlantic and Gulf Coastal Plain, and the Southern Appalachian region.

### The Coastal Plain region

The Coastal Plain region includes the wide coastal area extending across the Southeastern States bordering the Atlantic Ocean and the Gulf of Mexico. It reaches inland to the Southern Appalachian region, which it surrounds on the east, south, and west. Along the Mississippi River a wedge-shaped area extends to southwestern Kentucky. It comprises a strip about 100 miles wide across eastern Virginia and the eastern Carolinas, includes the southern two thirds of Georgia and Alabama, all of Florida, more than half of Mississippi, a narrow strip across western Tennessee, and a relatively small area in Kentucky. Most of the soils of the area are derived from unconsolidated sands and clays of marine origin. Relatively narrow strips of alluvial soils follow the principal streams and there is a fairly large belt of loessial soils bordering the Mississippi River alluvial plain on the east.

The Coastal Plain contains five distinctive subdivisions as follows:

1. The low coastal Flatwoods front the Atlantic and the Gulf. The soils here are mostly sands and sandy loams, with many wet areas and scattered patches of peat and muck.

2. Inland from the Flatwoods is a broad undulating to gently rolling area known as the Middle Coastal Plain. This extends from Virginia to Mississippi. Here the soils are mostly well-drained sandy loams rising to inland elevations of around 200 to 500 feet.

3. Inland from the Middle Coastal Plain is the Upper Coastal Plain. Its rolling to hilly soils range from deep, loose, droughty sands in the Sand Hills section to sandy loams in the western part, having subsoils ranging from friable sandy clays to heavy impervious clays.

4. A narrow undulating to gently rolling belt of clay loams and clays derived from calcareous chalk runs in a northwesterly direction across central Alabama and for some

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[1] Regional Conservator, Soil Conservation Service.

distance into central Mississippi. This is known as the Black Belt. Most of its topsoil has been removed by erosion.

5. West of this area and bordering the eastern side of the Mississippi alluvial plain is a belt of loessial silt loam which extends south from southwestern Kentucky across western Tennessee and Mississippi to the vicinity of Baton Rouge, Louisiana.

## The Southern Appalachian region

The Southern Appalachian region includes nearly all of Kentucky, the eastern two thirds of Tennessee, the northern third of Alabama and Georgia, the western half of the Carolinas, and the western two thirds of Virginia. The region is generally hilly to mountainous, but it includes the following five distinct subdivisions:

1. The rolling Piedmont Plateau runs in a belt a little more than 100 miles wide between the Atlantic Coastal Plain and the Blue Ridge Mountains from northern Virginia into east-central Alabama. Inland, it reaches elevations of about 700 to more than 1,000 feet where it joins the Blue Ridge Mountains. The Piedmont soils differ widely in character, having been formed by decay of the underlying crystalline granitic rocks, quartzite, slate, schist, basic igneous rocks, and Triassic shale and sandstone. They consist mostly of clay loams and sandy clay loams, generally with well-established drainage.

2. The Blue Ridge Mountains extend as a narrow belt from northern Virginia to northeastern Alabama. The area reaches its greatest width and highest elevations in western North Carolina and eastern Tennessee. The soils of the mountains are derived from acid granitic rocks, basic igneous rocks, and schists.

3. The Great Appalachian Valley with its included ridges extends from northern Virginia across eastern Tennessee and northwestern Georgia into central Alabama. From the undulating to gently rolling valley floor, hills and ridges rise abruptly to elevations of about 700 to 1,000 feet. The fertile valley soils are derived mainly from limestone. Those on the hills are derived mainly from cherty limestone, shale, and sandstone. Clay loams of good drainage predominate. Erosion is especially severe on the rolling areas, especially in the southern part.

4. The Appalachian Mountains and Plateau extend across eastern and central Kentucky and Tennessee into central Alabama. Elevations in the mountains reach 3,000 to 4,000 feet west of the Appalachian Valley, but decline toward the west. The Plateau sector to the west is cut in places by deep stream valleys bordered by steep, rough lands. The soils have been derived from sedimentary rocks, chiefly sandstones and shale.

5. West of the Appalachian Plateau sector the Highland Rim area extends southward from southern Kentucky across Tennessee into northern Alabama. It is generally rolling to hilly, with occasional plateau-like areas, some of which are pitted with lime sinks. Many streams have deeply entrenched valleys with very steep slopes. Soils generally have been derived from limestone and shale. The soils of the famous Lexington Bluegrass section in Kentucky and the Nashville basin in Tennessee have been formed from limestone relatively high in phosphorus and are highly productive where protected from erosion.[2]

## Agriculture

Cotton is grown to some extent over most of the region, with the exception of the northern part, the mountains, and peninsular Florida. It is of secondary importance, however, outside the Mississippi Delta, the Southern Piedmont, Upper Coastal Plain, and the loessial area. Bright tobacco is the principal money crop in certain parts of Virginia, North Carolina, South Carolina, Georgia, and Florida. A small section of Georgia and Florida produce approximately

[2] For further detail of these southeastern subdivisions, see *Soil Conservation* (McGraw-Hill Company, New York).

one third of all the shade tobacco. Burley tobacco is grown in the limestone section of Kentucky and Tennessee. Peanuts are grown on sandy lands in the coastal plain sections of North Carolina, Virginia, Georgia, Alabama, and Florida. Pecans are produced commercially in the southern part of the region, especially in Georgia, Alabama, Mississippi, the Carolinas, and northern Florida.

Peaches are an important commercial crop in parts of Georgia, South Carolina, North Carolina, and Virginia. Along the Atlantic Coast from Virginia to Florida and to a less extent in Alabama and Mississippi, the growing of early Irish potatoes is a major enterprise. On the sandy soils of this same area, general truck crops including corn, tomatoes, and beans are also produced commercially.

Florida produces about 40 per cent of the nation's citrus fruit. Tung oil production is being developed in the coastal sections of Alabama, Florida, and Mississippi. A variety of winter vegetables are grown extensively in the Florida Everglades.

The uplands and mountainous sections produce apples, peaches, and berries on a commercial scale. Watermelons, cantaloupes, and vegetables are important products of the Coastal Plain section.

In Kentucky, the bluegrass region is famous for the breeding and training of race horses. It also produces much tobacco, corn, and grass for grazing.

In south Georgia and in various other localities, as in the Charleston, South Carolina, area, many of the tomato, cabbage, and other plants used by northern truck growers are produced. During World War II, the production of bulbs expanded rapidly in Florida and some other states of the Southeastern Region.

Livestock farming, including dairying and the production of beef cattle, hogs, and sheep, is most highly developed in Kentucky, Tennessee, Virginia, and western North Carolina, and more recently in the Black Belt and loess areas of Alabama and Mississippi. Livestock and dairy farming was given a marked impetus with the extensive use of kudzu, the lespedezas, and various new legumes and grasses brought about under the soil conservation program.

With the growth of the livestock industry has come an increase in the number of milk-processing plants, freezer plants, and other facilities for handling and processing livestock.

The Coastal Plain section, with its abundance of peanuts, sweet potatoes, and corn, is well adapted to the commercial production of hogs. Harrisonburg, Virginia, has long been an important center for poultry production, including broilers and turkeys. Recently a large-scale broiler industry has developed around Gainesville, Georgia. Poultry production is also important in many other areas, notably in Tennessee and North Carolina.

### Forest products

Forest products are an important source of income to many farmers. Lumber, poles, piling, posts, cross ties, and veneer are among the valuable products from southern farm woodlands. In recent years, there has been a great increase in the wood pulp industry in the Southeast. A number of pulp mills are active along the South Atlantic and Gulf Coasts and furnish a market for pulp wood. Almost the entire naval stores industry of the United States is in the Southeastern

Region.   The value of naval stores at the Savannah, Georgia, market is now more than $27,000,000 annually.

## Population

The total population of the Southeastern Region in 1940 was 23,948,562, of which 16,278,646, or 68 per cent, was rural.   The density of population for the region as a whole was 58 persons per square mile; that for the rural areas, 39.4.

In the coastal areas the rural population is only 26.7 persons per square mile. The Piedmont Plateau has the highest density of population—81.2 per square mile, of which 57.1 is rural.

### IMPORTANT PROBLEMS AND THEIR SOLUTION

#### Maladjustments in land use

Agriculture in the Southeastern Region has largely centered around row crops. Little attention was formerly given to improved pasture, except in certain sections of Kentucky, Tennessee, and Virginia.

When farmers saw their hill lands becoming "thin" or "worn out," they cleared new fields for cotton, corn, or tobacco and allowed the exhausted land to revert to woods.   After a few years this land might again be cleared and cultivated.   Numerous fields have been through this cycle several times.

Coupled with disregard for slope and erodibility was the general practice of straight-row cultivation.   Many thought that proper drainage was possible only if the rows ran up and down hill.

The census of 1880 refers to losses from erosion.   Hillside ditches and contour cultivation, then known as "horizontalizing," were beginning to be used as measures for preventing erosion.   At the present time, these practices are generally used in some sections, but straight-row farming is customary in many others.

#### Needed land-use changes

In 1945, the governing bodies of 177 southeastern soil conservation districts, assisted by agricultural workers, estimated land-use changes needed in their districts.   In making these estimates, they were guided by sample conservation surveys indicating the capabilities of the land.   They also considered the economic needs of the farmers.   When these estimates were tabulated and expanded to areas of similar characteristics, the following picture of needed land-use changes was brought out:

|  | Acres—Increase or Decrease | Per cent—Increase or Decrease |
|---|---|---|
| Cultivated | −1,022,088 | −2.0 |
| Idle | −7,947,880 | −100.0 |
| Perennials | +9,824,056 | |
| Total cropland | +854,088 | +1.0 |
| Pasture | +7,994,203 | +36.0 |
| Woodland | −4,459,921 | −8.0 |
| Wildlife land | +1,717,619 | |
| Miscellaneous | −6,105,989 | −35 |

The collective thinking of more than 800 farmer members of the governing bodies of soil conservation districts recognized the need for larger acreages of perennial hay and grazing crops, such as kudzu, sericea, and alfalfa. When established on erodible areas and on land not suited for row crops, these perennial crops furnish effective protection against erosion. The district leaders also urged that the acreage of woodland be decreased and that productive use be found for idle farmland. As a result of these changes total cropland would be increased by about 1 per cent.

Of the land in farms in the Southeastern Region, 59.6 million acres are classed as cropland by the 1940 census. Of this area, cotton, tobacco, and peanuts, the principal cash crops, and corn, the principal subsistence crop, occupy 34.5 million acres.

There were 3.9 million acres of small grain and 7.9 million acres of idle cropland. This leaves approximately 13.3 million acres for all other crops. There were 22.3 million acres of pasture and 56.4 million acres of woodland.

Although row crops still predominate in southern agriculture, there is a decided trend toward more small grain and pasture, and a corresponding decrease in row crops. The estimates by district governing bodies of needed changes in land use reflect this trend.

## Advantages of adjustments

Use of land according to its capabilities means that steep and badly eroded land now in cultivation should be converted to other uses. This would involve also the conversion of a certain amount of woodland and pasture to cultivation.

It might be assumed that such adjustments in land use would reduce the amount of cropland and our crop production, but the opposite actually would be the case. Estimates based on a large number of conservation surveys indicate that approximately 9 per cent of the present cropland should be put to other uses, principally woodland, pasture, and perennials. Provided all the land in the region were used according to its capabilities and were treated according to its needs, it would be possible to increase cropland by approximately 7.6 million acres and still have all the land used safely. This could be done without converting any of the present pasture land to crop use. Pasture land was not considered as a source of cropland because of the present helpful trend toward increased pasture.

Although the Southeast still has this additional land available for crops, it will be a big task to make these adjustments by converting cropland to other uses, and clearing woodland for crop use.

In addition to these conversions, productivity of some of the present cropland can be greatly improved by simple farm drainage. An undertermined amount of new land could also be brought into cultivation in the coastal areas by means of large community drainage projects.

## Conservation benefits

These adjustments in land use, together with application of the necessary soil and water conservation practices, have proved profitable to those who are prac-

ticing them. A study in seven Southeastern areas, with widely different conditions, shows an average increase in gross income of $14.39 per acre on farms where most of the needed conservation practices and land-use treatments have been applied.

## Soil erosion

The Southeastern Region as a whole is probably the most seriously eroded of any area of comparable size in the United States. There are three main causes for this: first, the row-crop system of agriculture that is practiced throughout a large part of the region; second, the long growing season that leaves the land exposed to erosion during most of the year; and third, the heavy, high-intensity rainfall. Much of the summer rainfall comes as thundershowers with heavy rains of high intensity.

In the Piedmont area both sheet erosion and gully erosion are further advanced than in any other section. Deep gullying is common at or above the heads of drainageways, and sheet erosion has been almost universal. In fact, sheet erosion is so common that people have the mistaken belief that the extensive red clay soils are normal soils. Actually, they are subsoils exposed by erosion. Because of the inherent fertility of many of these subsoils, it has been possible to continue them in cultivation for a time after the topsoil has been lost. As a result, Piedmont streams are colored by the red clays washed into them from adjacent uplands.

Erosion has not been generally widespread in the Blue Ridge, because the greater part of the area is forested. On the small part in cultivation, sheet erosion is widespread and some areas are severely gullied.

In the Appalachian Valley, sheet erosion is more widespread and destructive than generally realized, and gully erosion is serious locally.

In the Appalachian Mountains and Plateau area, both sheet erosion and gully erosion are widespread.

Sheet erosion has gradually depleted the lands of the Highland Rim area in many localities, although the widespread use of grasses and legumes has somewhat retarded the loss of soil.

Erosion is negligible in the Flatwoods portion of the Coastal Plain, except locally, where sediment hampers drainage installations. It is a problem on some of the citrus-growing lands of Florida. Throughout the Middle Coastal Plain, erosion is fairly extensive, particularly as sheet erosion on cultivated lands. Both sheet erosion and gully erosion are more severe and more widespread in the Upper Coastal Plain. Some of the most spectacular, destructive gully erosion in the United States is found in certain parts of this area.

In the Black Belt, sheet erosion has been so severe and widespread that the underlying parent substrata have become exposed over extensive areas and the color of the soils has changed from black to grayish white, almost within a single generation.

In the loessial soil belt, destructive gully erosion occurs over large areas, especially in northeastern Mississippi. Sheet erosion is widespread, but owing

to the uniformity of topsoil and subsoil, its destructiveness has not been recognized generally until it has reached some depth. The development of gullies is greatly accelerated once they have cut through the loessial soil mantle into underlying sands and clays. Damage from sand debris washed from these gullies has ruined adjacent areas for further productive use. This deposition of erosional debris is particularly serious in parts of the Mississippi Delta lying immediately below these eroding hills.

*Economic effects.* It is impossible to evaluate fully the economic effects of erosion in the Southeastern Region. Among these effects have been the lowering of crop yields on the eroded land; increased cost of tillage and fertilization to maintain yields; abandonment of land for farming because of gullying and excessive sheet erosion; retirement of bottomlands from cultivation or pasture because of erosional debris from eroded uplands; siltation of industrial and community reservoirs by eroded material from areas upstream.

Widespread erosion has resulted in the abandonment for further production of clean-cultivated crops of much land with slopes in excess of 8 or 10 per cent. In many local areas only scattered cultivated fields remain. The income from such areas has declined greatly and has frequently necessitated the relocation of farm families. Deterioration of schools, churches, and other institutions has resulted.

As a result of the present soil conservation movement, which grew out of these erosion conditions, a greater portion of the land is being devoted to grazing crops and soil-improving cover crops. The acreage devoted to clean-cultivated cash crops is being confined more closely to the smoother, less erodible land. Other land formerly used for row crops is being devoted to close-growing feed crops with which to support a steadily increasing livestock industry.

*Erosion control and soil conservation.* In the first article of this series, Dr. Hugh H. Bennett, Chief of the Soil Conservation Service, describes the system of classifying land according to its capability upon which the nationwide program of soil conservation is based. Dr. Bennett also explains the necessity for many different practices to meet the requirements of eight different classes of land. At this point a brief description of the methods applied to examples of each of these land classes in the Southeast will help to illustrate the practical progress of erosion control and soil conservation throughout the region.

The well-drained, nearly level desirable soils of Class I land can be kept in productive condition for an indefinite period if sufficient cover crops are grown in the cropping system to maintain the organic matter content of the soil. Reseeding legumes such as grandiflora vetch, wild winter peas (*Lathyrus hirsutus*), and bur clover offers many advantages on this class of land, if managed so as to allow the legumes to make sufficient seed to ensure natural reseeding.

Class II land usually has sufficient slope to require terracing, contour tillage, and protected outlets into which water from terrace ends may be discharged. Most farmers are willing to accept these as essential soil conservation practices on Class II land, but there is need to develop rotations that keep half the land covered while the other half is cultivated.

A simple 2-year rotation of peanuts the first year, followed by fall-seeded oats and vetch, with a summer cover crop of crotalaria the next year, proved effective on Class II land at the Southern Piedmont Conservation Experiment Station at Watkinsville, Georgia. Another successful rotation that has been widely adopted consists of oats and lespedeza the first year, lespedeza hay the second year, corn the third year, with a winter legume seeded in the fall the third year, and cotton the fourth year.

Land in capability Class III has slopes that require terracing, with proper water disposal at terrace ends, contour tillage, and a rotation that keeps two thirds of the land under effective cover while the other third is cultivated. A rotation that includes oats and lespedeza the first year, lespedeza hay the second year, and cotton or corn the third year is the minimum that can be depended on for protection of land in this class.

On land in Class III, the rotation is more effective when arranged in strips on the contour. Arrangement in strips has the following advantages: first, crop acreages are more easily balanced on farms where fields vary widely in size; second, plowing of a whole field at any one time is unnecessary; third, when terraces break or overtop, strips of protective vegetation bring the water under control and often greatly reduce field damage; and fourth, cultivation, including land preparation and drilling of small grain, is more easily kept on the contour when the entire field is not used as an operating unit for equipment.

Preliminary results on experimental runoff plots indicate that land in Class IV may be safely cultivated every three or four years if kept under a cover of deep-rooted perennial legumes such as kudzu, lespedeza sericea, or grass and alfalfa the rest of the time. Kudzu almost completely protects the ground surface and restores itself from plants that survive cultivation of the row crops.

Steeper slopes that are placed in capability Classes VI and VII are not suitable for cultivation and require perennial cover for their protection. This cover may be pasture sod, perennial legumes such as kudzu or sericea, or woodland cover, according to the needs of the farmer.

Erosion is not a serious factor on land in Class V, primarily used for grazing, or on land in Class VIII, which is nonagricultural land suitable mainly for wildlife and recreation.

Field borders between cultivated land and woodland present an erosion problem that can be met best by establishing a border strip of an effective perennial ground cover such as lespedeza sericea. When combined with an adjacent strip of bicolor lespedeza for game food, this type of vegetation prevents erosion and also furnishes cover for wildlife.

### *Water conservation and control*

The average annual rainfall of 50 to 60 inches in the Southeastern States, if properly distributed, would be sufficient to supply both agricultural and industrial needs. Unfortunately, this optimum condition seldom exists. Even with adequate rainfall, other elements that contribute to water deficiencies include: (*a*) accelerated runoff resulting from improper land use and inadequate

PLATE 4. CONTOUR STRIP OF LESPEDEZA SERICEA IN CULTIVATED FIELD, WITH CORN ABOVE AND TOBACCO BELOW, IN RICHMOND COUNTY, NORTH CAROLINA

cover, (b) failure to maintain the soil structure, with resultant loss of its capacity to absorb and store water, (c) overdrainage in some areas, and (d) failure to conserve or control surface and ground water resources to meet seasonal requirements and demands.

Among the causes of water wastage are the clean-tilled system of agriculture of the Southeast, exploitation of timber resources, frequent overgrazing and burning of timber land, overgrazing of existing pasture, and reduction of reservoir storage capacity by sedimentation resulting from erosion.

Water wastage has resulted in lower production and quality of crops due to lack of moisture, depletion of ground water resources in agricultural, industrial, and municipal areas, added cost of industrial production, increased costs of providing water for municipal needs, and decreased tax revenue.

The soil and water conservation program being applied in soil conservation districts, with the assistance of the Soil Conservation Service and other federal and state agencies, is at present the most effective means of overcoming these problems. This program varies according to the needs in different parts of the Southeastern Region, but includes improved land-use practices, soil management, strip cropping, terracing, contour cultivation, establishment of adequate ground cover, and the conservation and management of water resources, as provided in complete farm conservation plans in the districts.

*Farm ponds.* Farm ponds are essential in all parts of the region where livestock is supported on farms and where running water is not available. There are areas in the Southeast where it is difficult to construct and maintain ponds that will provide a constant supply of stock water. If surface or artesian water is not available, ground water offers the only means of supply in such cases.

Fish management in farm ponds supplied a healthful change of diet not frequently available to most farms of the Southeast. Successful fishponds require correct stocking, fertilization, adequate erosion control, and avoidance of excess waters. Ponds managed without water weeds are not a menace to public health and provide better fishing than those infestes with weeds.

Numerous farm ponds and small artificial lakes are needed throughout the Southeast to provide a supply of water for supplemental irrigation where truck crops and fruit are produced. Many structures of this type are being built in the coastal areas, and the practice is gaining favor in upland areas. The farm pond if near farm buildings, provides a supply of water that is available for fire control to a limited extent. Ponds are also of value as a source for spray water in many areas where fruits and vegetables are produced.

In water conservation and water use lies, also, the welfare of many birds and mammals—waterfowl, shorebirds, and fur-bearers. With help from the biologist, the engineer, and the soil scientist, land management of wet soils best suited for these forms of wildlife is becoming profitable in some areas.

*Flood control.* Approximately 45 per cent of the land in the Southeast is open land, an appreciable amount of which is abandoned or severely eroded. About 55 per cent of the region is woodland, most of which is improperly managed, resulting in poor ground cover. Because of these conditions, the flood problem

in the Southeast is serious and widespread. Frequent floods in many minor and major drainage basins cause excessive damage to both agricultural and urban property.

In addition to direct damage caused by flood waters, costly sedimentation damage is sustained in many areas. About 80 per cent of the land area in the region is silt-producing.

Frequent and excessive rainfall with resultant runoff of high velocities causes severe erosion in virtually all upland areas in the Southeastern Region. The flooding of bottom land and the deposition of erosional debris cause irreparable damage.

Reservoirs for power development, for industrial and municipal purposes, and for flood control constructed on major streams and their tributaries throughout the Southeastern Region have suffered disastrous loss of storage capacity from the silt load transported by streams.

Most of the streams that originate in the upland areas eventually deposit heavy loads of sediment in harbors and ship basins at their mouths. As a result, continuous and expensive dredging operations are required to keep the waterways and harbors in usable condition.

The many flood-control problems that have been mentioned are a serious menace to the economy of the region. The general application of effective soil and water conservation measures by the soil conservation districts is affording some relief from local floods. To be of material value, however, this work must be expedited, concentrated, and supported by a national flood-control program.

To date, the Congress has authorized works of improvement for waterflow retardation and soil erosion prevention in aid of flood control on four major watersheds in the Southeastern Region. These are the watersheds of the Yazoo and Little Tallahatchie Rivers in Mississippi, the Coosa River above Rome in Georgia, and the Potomac River[3] in Virginia. At the present time, overall plans are being developed for selected minor watersheds within these areas preparatory to initiating the action program in cooperation with local soil conservation districts.

*Drainage.* The 1940 drainage census shows that there are 1,236 organized drainage districts, comprising 10,770,818 acres, in the Southeastern Region. A substantial amount of this land still needs improved drainage. The capital invested by landowners in the various drainage enterprises to 1940 represents an expenditure of $87,451,459 to provide major outlet drains in these districts. In addition to the organized drainage districts, it is estimated there are 9 million acres of potentially good agricultural land that needs drainage improvement.

In the majority of cases, good field drainage was not established because trained engineers were not available locally to do the layout work. The large ditches were constructed, yet crop failures continued. The maintenance-tax levies were rejected, and major outlets deteriorated.

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[3] The Potomac watershed includes also areas in West Virginia and Maryland, which are in the Northeastern Region.

The principal drainage problem areas in the Southeastern Region and the most difficult drainage engineering problems may be summarized as follows:

1. In tidal marshes and old rice fields along the Atlantic Coast, outletting against tides and the diking out of salt water are the major problems. 2. In the Flatwoods, the most difficult engineering problems are associated with flat grades and deep sands. 3. In the loessial section, in the states bordering on the Mississippi River, silt control problems are outstanding. 4. The discharge of loessial silt from the hills above the Delta of the Mississippi and flat grades in the delta are major technical problems of design and maintenance. 5. In the valleys of the Piedmont and Mountain section the flash runoff requires larger drainage coefficients than are usually employed. Main channel improvement, including snagging and bar removal, diversion of hill water, and a drainage system on the bottomland are the chief engineering problems. 6. The Everglades of Florida and areas of organic soils along the coast of North Carolina need closely controlled drainage systems to reduce subsidence and soil burning.

Undrained land is found on many farms. Frequently it is necessary for two or more farmers to use the same outlet. This requires cooperative effort on the part of these farmers in providing main outlets for field ditches or tile systems. Where only a few farmers are concerned, no drainage district may be needed. If the group drainage system is in a soil conservation district, local drainage specialists of the Soil Conservation Service are available to advise what annual maintenance may be necessary. Where a large number of farmers and large acreages are involved, it is desirable to organize a drainage district under state laws.

After the major drainage outlet facilities have been provided, the field drains must be planned, constructed, and maintained. The substitution of tile for open ditches will help to increase the size of fields, thereby making it easier to apply mechanized production methods. In certain truck-growing sections along the Atlantic Coast, it is estimated that open ditches take 15 per cent of the land area. Tile drainage, where feasible, also eliminates annual cleaning of ditch banks.

All structures and soil conservation practices require maintenance to protect the original investment. Drainage ditches or tile systems are no exception. Natural vegetation begins to cover the sides of ditches as soon as construction is completed. Silt begins to drift into new ditches with the first rains. Eroded material from the drainage basin washes into the ditches. All these tend to retard flow in the ditches. It is evident, therefore, that both maintenance and preventive measures should be provided in the original plans for all drains.

It has been found in the delta area of Mississippi that kudzu on the banks of canals will control willows and other undesirable vegetation. Bermuda grass also helps to control undesirable vegetation and stabilize the cut slopes, when mowed several times a year.

*Supplemental irrigation.* Supplemental irrigation has increased crop yields in the truck and citrus section of the Southeastern Region. Here, the annual rainfall ranges from 40 to approximately 60 inches. In this area dry periods occur during the crop season almost every year.

The truck growers in the vicinity of Charleston, South Carolina, estimate that truck crop yields can be increased from 25 to 100 per cent by irrigation. In fact, the interest in soil conservation districts there arose largely from the need for assistance in irrigation and drainage. The citrus growers in Florida also report that supplemental irrigation increases the yield and quality of fruit. Work plans for the districts in that section outline irrigation as a major need. According to the experience of citrus grove managers, one dry year affects the yield and quality of fruit for the succeeding three crops.

The district supervisors of the recently organized Eastern Shore Soil Conservation District of Virginia report in their work plan that irrigation is a major requirement. There has been an increase also in the number of irrigation systems planned in some peach-growing sections of the region.

The major sources of irrigation water are ground water wells, deep wells, impounded reservoirs, free flowing streams, and natural lakes. Recently the damming of coastal inlets subject to tidal influence has been successful in creating a fresh-water reservoir in place of a salt marsh. Because of the shallow water in these reservoirs, evaporation must be carefully considered in planning.

Water is generally distributed to the plants through pipe and nozzles under pressure. The original cost of this method is high but it ensures better distribution of water on the fields. Since the need for irrigation is not continuous, the use of portable systems is practicable.

Rooting depths of crops and water-holding capacities of soils are two factors which must be known in every instance where irrigation is planned. Through a knowledge of these, the depths of penetration and the amount and frequency of water applications are determined.

### Special problems

The preservation and use of organic soils—peats and mucks—present a special problem in the Southeastern Region. This problem involves determination of the height at which the water table must be maintained to ensure minimum oxidation and subsidence of the soil material and optimum plant growth. Also involved is a determination of which areas of organic soils should be developed for agriculture and which should be used primarily for water storage.

Another problem involves the use and management of the more sandy soils, particularly for citrus fruits and to some extent for peaches. This is a problem of preventing soil washing on the slopes and of maintaining soil fertility. The inclusion of crotalaria in rotations has made possible the agricultural use of much of this land that previously was not considered suitable for crop production.

# SOIL CONSERVATION AND GOOD LAND USE IN THE UPPER MISSISSIPPI REGION

R. H. MUSSER[1]

The Upper Mississippi Region comprises the eight states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. It lies almost wholly within the physiographic region of the Great Central Lowlands. Exceptions are the southern parts of Missouri and Illinois, which fall in the Ozarkian Highlands; the Appalachian Highlands in southern Indiana and southeastern Ohio; and the Great Plains Region in the Red River Valley of the North. The central and western parts of the region are prevailingly prairie country, although a large area along the northerly, easterly, and southerly borders originally was timbered.

Predominantly, the region is an undulating or gently rolling plain with slopes ranging from 4 to 10 per cent. Over much of the upper lake region the topography is rolling to hilly. This is also true in the territory adjacent to and in the Appalachian and Ozarkian Highlands. Here slope gradients range from 12 to 50 per cent. Strips of rolling to broken or hilly country with many slopes too steep for cultivation commonly border the larger streams. Elevations range from about 500 feet above sea level in the south to over 1,900 feet in the north. Most of the region is between 1,000 and 1,200 feet above sea level.

The climate covers wide seasonal extremes of temperature. The annual precipitation is only 20 inches in the northwest and 45 or more inches in the southern part. Distribution of rainfall is fairly uniform throughout the growing season, which ranges from 110 days in the northern part to 180 days in the southern part.

The soils of the region are dominantly silt loams, but there are also a variety of loams, silty clay loams, and sandy loams, and in the Great Lakes section, deep sands. They are derived from glacial till; loess, lake, and river deposits; and disintegrated shale, sandstone, and limestone. The region has numerous land areas each of which has more or less uniform soils, topography, and agricultural adaptations.

The agriculture of the region is based on corn, small grains, and forage, which are sold as cash crops and also used for livestock production and dairying. Limited areas specialize in fruits, vegetables, sugar beets, potatoes, and tobacco. Subsistence farming dominates in the Ozarkian and Appalachian Highlands and in the cut-over region of the Great Lakes. Dairying is especially important on the fringe of the Corn Belt, and in the northern part adjacent to the cut-over area.

The Upper Mississippi Region is an important source of foodstuffs in the United States. Although it contains[2] only

15 per cent of the land area of the United States and
20 per cent of the land in farms, it has

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33 per cent of the cropland harvested. In 1941 it produced
49 per cent of the tonnage of all grains produced in the United States and
45 per cent of the total milk produced on farms. It accounted for
49 per cent of the meat produced in 1940, which included
64 per cent of the pork,
38 per cent of the weight of cattle and calves (after deduction of cattle shipped in),
19 per cent of the weight of sheep and lamb,
40 per cent of the weight of chickens, and
28 per cent of the turkeys. In this region,
39 per cent of the eggs were produced.

To round out meat and bread diet, the region produced in 1941

72 per cent of the sweet corn,
52 per cent of the canning peas,
47 per cent of the cucumbers for pickles,
36 per cent of the table beets for canning,
33 per cent of the canning tomatoes,
28 per cent of the cabbage and kraut, and
21 per cent of the snapbeans for canning.

The region also does its bit toward producing vegetable oils. In 1941 it produced

92 per cent of all the soybeans harvested,
60 per cent of the flaxseed, or
38 per cent of the tonnage of oil seeds.

The Upper Mississippi Region contains a little more than one fourth of the population of the United States—35,741,574 in 1940. It has a ratio of urban to rural population of 6 to 4. The heaviest concentration of this population is in Illinois, Ohio, and Michigan. All sections except southern Missouri and the cut-over area of the Great Lakes are well supplied with villages of 1,000 or more population. There are nearly 2,000 villages with a population of 1,000 to 5,000; 400 towns with a population of 5,000 to 20,000; 90 cities with a population of 20,000 to 50,000; and 45 cities with a population of more than 50,000.

This large urban population places a heavy demand for food and fiber on the surrounding rural areas. It also furnishes a ready market for farm produce and a ready source of farm supplies and equipment.

### MALADJUSTMENTS IN LAND USE

A recent survey of farmland use throughout the region indicates that approximately 12 million acres of crops are being grown on land of capability Classes V, VI, and VII. These areas are too wet, too steep, too eroded, too low in fertility, or too low in moisture-holding capacity for satisfactory production of cultivated crops. They should be shifted to pasture or woodland. This misuse of farmland in the Corn Belt and the areas bordering on it is especially prevalent on steep slopes adjacent to streams. In the cut-over area, also, many acres of land too low in fertility or too low in moisture-holding capacity are utilized for crops. This same survey shows approximately 30 million acres of farmland suitable for cultivated crops (Classes I, II, and III) now being utilized for pasture or woods.

It should be possible, therefore, to switch some cropland with pasture or woodland for better land use. The solution, however, is not so simple as this information might indicate. For example, many dairy farmers must retain land in Classes I, II, or III in pasture.

Table 1 lists existing and desirable cultivated and grazing land acreages for the region. This shows the need for a reduction of about 11 million acres in the total cropland area and an increase of 3 million acres in pasture land. The shifts include removal of all cultivated crops, except orchards, from Classes IV to VII, and utilization of such land for pasture or woodland. Some of the pasture on land Classes I, II, and III would be converted to cultivated crops. These shifts should not reduce the total cultivated crop production, since land in Classes I to III is generally more productive than land in classes IV to VII. Improved

TABLE 1

*Existing and desirable land use for farmland in the Upper Mississippi Region*

| LAND CLASSES | CROPLAND | | PASTURE LAND | |
|---|---|---|---|---|
| | Existing | Desirable | Existing | Desirable |
| | *million acres* | | *million acres* | |
| Land suited for cropping (Classes I, II, and III) ...................... | 108.6 | 124.2 | 22.5 | 6.9 |
| Land suitable for limited cultivation (Class IV)........................ | 15.0 | 0.05* | 6.7 | 21.65 |
| Land suitable for permanent vegetation (Classes V, VI, and VII)...... | 11.8† | 0.07* | 12.8 | 17.0 |
| Nonproductive land, wildlife areas (Class VIII)....................... | 0 | | 0 | |
| Change............................. | | −11.0 | | +3.5 |

* Orchard lands.
† Some should be shifted to pasture land, some to woodland.

methods of pasture renovation will enable the farmer to get more forage from his pasture land.

Some farm units are too small, and the farmer is forced into excessive use of his land for high-valued crops. This is particularly true of farm units in the Corn Belt on sloping land adjacent to streams. It is also true on some of the inferior soil areas, especially the deep sand areas of central Wisconsin, northern Michigan, and Minnesota. These rolling lands and inferior soils, in Classes IV, VI, and VII, are not adapted to the usual Corn Belt type of agriculture. They must be utilized for a more extensive type, based primarily upon production of forage or timber.

Another poor practice is growing too many clean-tilled crops and not enough grasses and legumes. This intensive cropping system is destroying soil structure, reducing yields, and increasing tillage costs.[3] It has been shown that a good rotation of corn, oats, alfalfa-brome, alfalfa-brome in a 10-year period increased the yields 37 per cent over previous production. For the same period,

[3] Yoder, R. E. Soil structure is key to yield. *Successful Farming* 14(11): 23–25. 1946.

a corn-oats rotation with the straw and stover removed showed a 38 per cent decrease in productivity, and continuous corn, a 64 per cent decrease. These Ohio results indicate that cropping systems can be changed to include more grasses and legumes and still maintain the needed levels in grain production.

In some areas a high percentage of tenancy with short-term leases contributes to the intensive cropping. Such leases give no incentive to improvement of the land. In some places the tenant is charged an extra $5 an acre rent for each acre maintained in grass.

### SOIL EROSION

Soil erosion is common on both cropland and pasture land throughout the region. This is true even in the very gently sloping to nearly level Lake Plain areas of Michigan, Indiana, Ohio, and Minnesota. Under present conditions, the most rapid rate of erosion is occurring in the Corn Belt proper, especially in Iowa and Missouri in areas adjacent to the Missouri River. In southeastern

TABLE 2

*Estimated average annual erosion loss on cropland by states*

| STATE | EROSION LOSS | STATE | EROSION LOSS |
|---|---|---|---|
| | *inches* | | *inches* |
| Illinois...................... | 0.063 | Minnesota................... | 0.05 |
| Indiana...................... | 0.034 | Missouri..................... | 0.088 |
| Iowa.......................... | 0.151 | Ohio.......................... | 0.039 |
| Michigan.................... | 0.025 | Wisconsin................... | 0.074 |

Ohio, southern Indiana, and the Ozarks of Missouri, there is also a very rapid rate of erosion, but the acreage of cropland involved is rather small.

Probably the greatest contributing cause of this erosion is the clean-tilled crop type of agriculture. Areas continually producing corn and soybeans and having slopes of more than two percent show heavy annual soil losses. Table 2 shows, by states, the average annual soil loss from cropland. These data are tentative, but they do represent the relative severity of erosion between states.

This erosion is removing many pounds of plant food from our farmlands. There is a significant report[4] on nutrient losses from two farming systems at Lafayette, Indiana. One is the prevailing system for the area and uses a 3-year rotation of corn, wheat, and meadow with light fertilization and straight-row cultivation. The second is the conservation system and uses the same rotation but includes heavy fertilization and contour cultivation. The losses during the first round of the rotation for both systems are shown in table 3.

The organic matter and nitrogen content of the eroded fraction was more than twice that of the original soil. This represents a serious loss, for there is good

[4] Bedell, G. D., Kohnke, H., and Hickok, R. B. The effect of two farming systems on erosion from cropland. *Soil Sci. Soc. Amer. Proc.* 11. 1946.

correlation between yields and organic matter content of any given soil.[5] Yield studies indicate that a soil loses from 4 to 8 per cent of its productivity for each inch of soil lost.

The full significance of such soil losses is unknown. We can estimate the loss in yields due to erosion, but we do not know the effect of the loss of plant nutrients on the nutritive value of the plants produced on these eroding soils. This may be the most serious item. Albrecht[6] says: "Basic to our life is our food. Food is the product of agriculture in the form of fabricated soil fertility. Our life is, therefore, built on the soil and our future life as it is to be readjusted in global dimensions dare scarcely disregard our soils in terms of their differences in fertility." Serious study of the effect of erosion on nutritive value of plants is needed.

It is possible to control erosion and still maintain the high productive level of the Corn Belt soils. To do this, however, will require a shift in the rotation

TABLE 3

*Losses of plant nutrients from cropland from two farming systems, Lafayette, Indiana*

| SYSTEM | LOSS PER ACRE | | | | |
| --- | --- | --- | --- | --- | --- |
| | Soil | Organic matter | N | $P_2O_5$ | $K_2O$ |
| | *pounds* | *pounds* | *pounds* | *pounds* | *pounds* |
| Prevailing.............. | 9,380 | 696 | 60 | 53 | 21 |
| Conservation........... | 2,786 | 212 | 13 | 15 | 9 |

to decrease corn and soybeans and include more grasses and legumes. Rotations can do much toward controlling soil losses.

If we consider the losses from continuous corn as 100, the losses from a 3-year rotation of corn, grain, and hay are 22, and those from a corn-grain-hay-hay rotation are 13. Even a rotation of corn-corn-grain-hay-hay, will reduce the losses to 25. Prairie soils and soils containing 3.5 to 5 per cent organic matter will require a minimum of 40 per cent of the cropland in grass and legumes to maintain good tilth and a high level of productivity. The timbered soil areas will require at least 50 per cent of the land in grass and legumes.

This shift to more grass and legumes will reduce corn acreage. It will not reduce the feed production per acre of land. In fact, it will increase the amounts of total digestible nutrients and protein as shown by some Ohio results[7] in table 4.

The addition of more forage crops is no problem in the dairy sections, but it

[5] Uhland R. E. Conservation farming insures yields. Mimeographed Release, Soil Conservation Service, U. S. Department of Agriculture and State Agricultural Experiment Stations.

[6] Albrecht, W. A. Soil fertility and national nutrition. *Jour. Amer. Soc. Farm Managers and Rural Appraisers* 8: 45–66. 1944.

[7] Thatcher, L. E., Volk, G. W., and Yoder, R. E. Principles of land use, conservation of soil and water resources, and the improvement and maintenance of soil productivity. Ohio Agron. Mimeograph No. 104: 25. 1946.

does raise a rather serious problem for the Corn Belt farmer.   He is not equipped with buildings and utilities to handle such an increase, nor is he equipped with the necessary knowledge on proper feeding of high-quality roughage rations.

Much research and education are needed on feeding roughages.   A start has been made at the Soil Conservation Experiment Station at Zanesville, Ohio. This station, in cooperation with the Ohio Agricultural Experiment Station, is experimenting with using small quantities of corn and grain and large quantities of high-quality roughage in the feeding of cattle.   The experiment has not been running long enough to permit release of data, but results so far have been very encouraging to those carrying on the work.

TABLE 4

*Crop yields and feed production from Fry Farm, Ohio Agricultural Experiment Station 1937–1943*

| CROP SEQUENCE AND MANAGEMENT* | 7-YEAR AVERAGE YIELDS PER ACRE | | | | | AVERAGE ANNUAL RATE FEED PRODUCTION PER ACRE | |
|---|---|---|---|---|---|---|---|
| | 1st crop | 2nd crop | 3rd crop | 4th crop | 5th crop | T.D.N. | Protein |
| | *bushels* | | *pounds* | | | *pounds* | |
| Continuous C, 2 T. manure........ | 46.0 | | | | | 2300 | 184 |
| C-W (Sweet Cl.), 4 T. manure..... | 74.3 | 33.0 | | | | 2680 | 260 |
| C-W-Cl, 6 T. manure.............. | 78.2 | 39.4 | 5640 | | | 2810 | 325 |
| C-W-A-A, 8 T. manure............ | 81.4 | 41.7 | 6890 | 9000 | | 3440 | 589 |
| C-W-A-A-A, 10 T. manure........ | 77 | 41.4 | 7180 | 9180 | 9140 | 3675 | 679 |
| C.C.W.A.A...................... | 70.9 | 65.7 | 31.4† | 6750 | 9060 | 3140 | 500 |

* C = corn, Cl = clover, W = wheat, A = alfalfa, T. = tons, T.D.N. = total digestible nutrients.

† Bushels.

Rotations alone will not do the job.   Soil conservation measures such as contouring, strip cropping, terraces, diversions, and structures must be used to support these good rotations.[8]

### WATER CONSERVATION AND CONTROL

No civilization can long exist without water, yet probably no other country is so wasteful of this valuable resource as is the United States.   But all water that runs off the land is not necessarily wasted.   If the water has been utilized properly before leaving the land it cannot be considered as wastage, provided it causes no damage farther downstream.   Excessive runoff on the upland, however, generally causes serious erosion, both to the land on which the rain falls and to the disposal systems used to carry the runoff to the large streams. Along with the wastage of water goes the irreplaceable loss of soil and plant

[8] Browning, G. M., Parish, C. L., and Glass, J. S.   A method for determining the use and limitations of rotations and conservation practices in the control of soil erosion in Iowa. *Jour. Amer. Soc. Agron.* 39: 65–73.  1947.
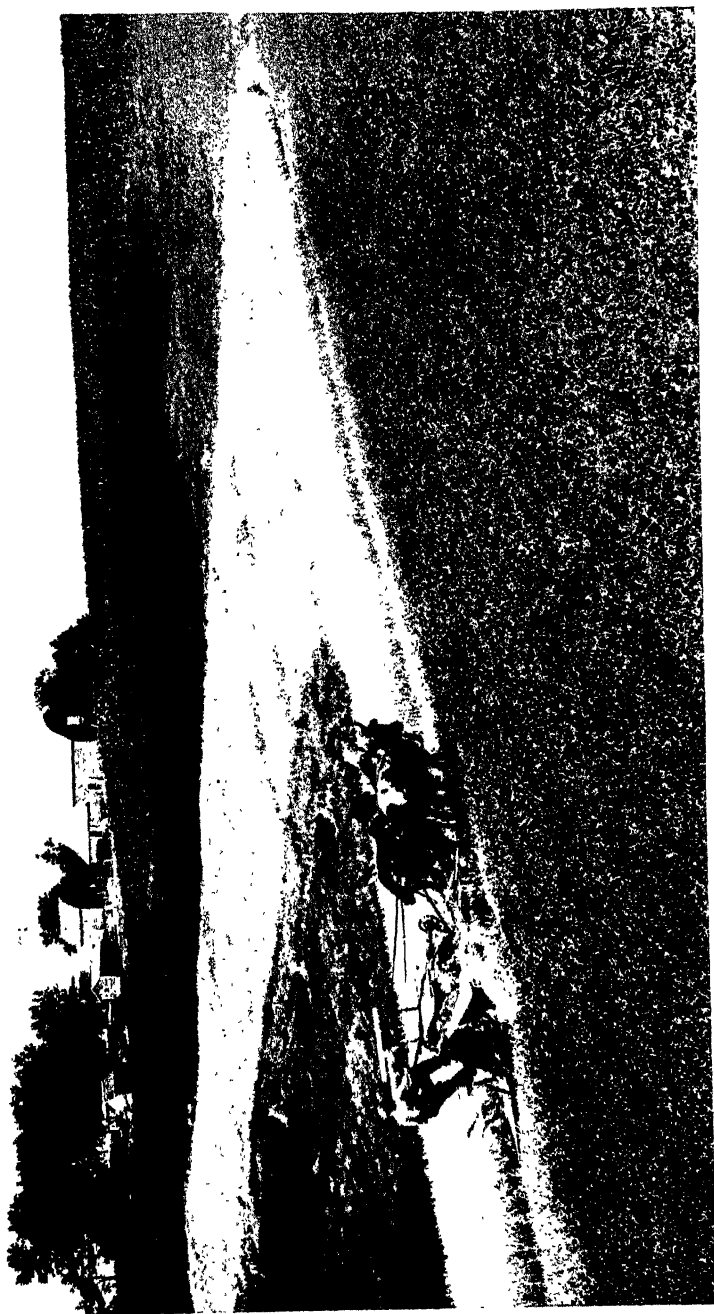
PLATE 5. CUTTING GRAIN ON A CONTOUR STRIP IN THE UPPER MISSISSIPPI REGION

food. The damage caused multiplies as the water moves downstream. The soil deposits on the fertile bottoms, smothering crops and often making hay and pasture valueless for as much as an entire season. These deposits fill drainage ditches and tile outlets, making drained land useless until repaired. The degree of wastage varies from watershed to watershed.

Water runoff is dependent upon the soil, rainfall (intensity, duration, and amount), cover on the land, and surface storage. Also, slope of the land and shape of the watershed greatly affect the peak runoff. Wide variation in runoff occurs yearly. In 1915 over 31 per cent of the rainfall in the Cedar River basin of Iowa left the watershed in the form of runoff, in contrast to only about $5\frac{1}{2}$ per cent in 1934. Records on the Scioto River in Ohio from 1910 to 1918 show a marked variation in runoff by months of the year. These records show a runoff of about 90 per cent of the average rainfall in March and only $5\frac{1}{2}$ per cent in September. In the loessial soil area of this region under present conditions, a 5-inch storm produces about 1.2 inches of runoff, whereas a 2-inch storm produces only about 0.3 inch of runoff. The story is different on the claypan soils. There a 5-inch rain produces about 3.6 inches of runoff, and a 2-inch rain about 1.3 inches.

Experiments in Ohio show that to produce 60 bushels of corn per acre requires 22 inches of water. In order at least to maintain the present production, every effort must be exerted to retain as much of the rain as possible on the land where it falls. Results of experiments have shown that the loss of water from land in continuous corn is almost four times that from the same land in alfalfa and almost twice what it would be if it were in a proper rotation. In many areas, corn yields will be increased as much as 10 bushels per acre by conserving moisture through the simple practice of contouring. Proper use of the land along with supplementing conservation practices can probably reduce the wastage of upland water and the annual runoff as much as 25 to 35 per cent.

Farm ponds are becoming increasingly important in this region as a source of stock water. Shifts to growth of more forage on Corn Belt farms will multiply the need for stock water many times. In some areas, noticeably the claypan soils of southern Indiana, southern Illinois, and northern Missouri, farm ponds are about the only reliable source of stock water. Ponds are easily constructed in these areas because it is easy to seal the fills against leakage, except where shallow, underlying bedrock is shattered. Increased production of livestock in the loess belt will require extensive building of ponds as a source of water supply. In these areas there will be a problem of sealing the fill against seepage as well as preventing silting damage.

The large urban population of the region means there is heavy industrial development. These urban areas require vast quantities of water. Many depend on deep wells. Recent experience indicates that this supply of water may be limited.

Water-level measurements in permeable glacial and alluvial deposits of sand and gravel indicate that recharge is received annually from precipitation and

stream floods in late winter and spring months.[9] Impermeable deposits do not show the same recharge. Continuous decline in water levels is shown only in heavily pumped areas such as the Mill Creek Valley at Cincinnati.

Increase in the amounts of pasture and woodland may offer some chance to increase water supplies through percolation of water. Reports from the North Appalachian Experimental Watershed show that soil moisture exceeds field capacity under wheat only during February and March; under pasture in January, February, March, April, November, and December; and under woods in all months except July, August, September, and October.[10]

### Floods and sedimentation

Since the passage of the Omnibus Flood Control Act of 1936, some 170 watersheds have been authorized for preliminary examination and survey in the Upper Mississippi Region. The flood and related problems of these watersheds vary with the types of valleys. These valleys range from the low-gradient, wide flood plains of the Ohio and Missouri, used for agricultural and industrial purposes, to the steep, narrow valleys of smaller streams, used principally for pasture.

When the word "flood" is mentioned, generally the mental picture is of a wide valley completely inundated, and of houses, barns, and other floating debris. This type of flood is spectacular and therefore gains considerable publicity. But small streams in narrow valleys often cause more serious damage. There are hundreds of small valleys for each large one. It has been estimated that 75 per cent of our flood damage is done in small valleys—areas which are seldom featured in our daily newspapers.

Damage done by flood waters is accompanied by damage from sedimentation. The sediment ranges from fertile topsoil to sterile sand and gravel. In western Iowa and western Missouri, the deep loess soils are extremely susceptible to both sheet and gully erosion. In this area, valleys have been known to receive 14 inches of sediment from the upland in a single rain. Western Illinois and western Wisconsin have a similar problem with a lesser degree of intensity. More infertile material is deposited, because some of the soils are residual sandstone. In the glaciated areas which comprise the remainder of Iowa and Minnesota, northern Missouri, northern Illinois, Michigan, and northern Indiana and Ohio, the soils are less pervious than the loessial soils. Here there is a problem of excessive runoff. The streams carry a high sediment content which damages water-supply and drainage systems. The remainder of the region is made up chiefly of residual soils. Bottom lands in these areas are not so fertile as those in the loessial and glacial areas, but they represent a relatively larger proportion of the cropland of the area. Consequently, damage is heavy.

Annual flood damages, which can be reduced by works of water-flow-re-

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[9] Schaeffer, E. J. Records of ground water levels in Ohio and their significance. *Engineering Experiment Station News, Ohio State University* 18(2): 26. 1946.

[10] Harrold, L. L. Soil water. *Engineering Experiment Station News, Ohio State University* 18(2): 19. 1946.

tardation and soil-erosion prevention, are estimated to be nearly one-quarter of a billion dollars in the Upper Mississippi Region. About 55 per cent of this damage is to agricultural property, crops, and pastures, on the tributaries of the larger streams. About 20 per cent of the damage is to crops and property on the main streams, and the remainder to urban areas and their water-supply systems.

Excluding power, recreational, flood-control, and irrigation reservoirs, this region has 550 water supply reservoirs with a value of about $98,000,000. These reservoirs are losing their storage capacity by sedimentation at varying rates up to 5 per cent a year. In addition, the annual cost of purifying water in this region is about $20,000,000, largely a result of excessive silt in the water.

Channel sedimentation in drainage ditches is another problem in this region. In the small Sny River watershed in the deep loess belt of Illinois, the annual cost of removing sediment from ditches and of constructing de-silting basins to prevent ditch filling is about $100 per square mile of drainage area. Also, channel sedimentation results in more frequent flooding of surrounding flood plain. On the Kickapoo River in Wisconsin, studies show that at the present rate of channel aggradation, annual urban flood damage will increase by 40 per cent in 20 years.

These damages from floods and sediment are all caused by excessive runoff and erosion. Results from experiment stations and other evidence available show that runoff of the smaller flood-producing storms can be reduced by as much as 35 per cent, whereas a much smaller reduction can be expected from the prolonged flood-producing storm of several days. Yet, on the average, a reduction of 15 to 20 per cent in runoff can be expected from the average flood-producing storm.

Through a proper land-use program, accompanied by the necessary supplemental practices, erosion can be reduced by as much as 60 to 75 per cent. Adequate water-disposal systems to carry the runoff water from the upland to the major streams are essential in such a program. In some areas, small detention dams are required; in others, structures to stop the advance of gullies are necessary. A program involving these general principles was started in 1946 in the Little Sioux River watershed of northwestern Iowa and southwestern Minnesota. Soil conservation districts in the watershed are directing the program. It is under the guidance of a 12-man committee made up of representatives of the respective district governing bodies in the watershed. The establishment of the land-use program is well under way. Contracts were let in July 1947, and construction is now under way for the major water-disposal systems in some of the subwatersheds of the Little Sioux.

*Drainage problems*

Approximately 27 per cent of the land area in the Upper Mississippi Region either is drained or is too wet for cultivation. This is over 40 per cent of the drained and wet land in the United States. There are over 54 million acres in legal drainage districts in the region. A large part of this area needs revaluation

of drainage benefits with rehabilitation of some drains, adequate maintenance of others, and abandonment of some.

The problem of drainage has raised considerable conflict between farmers and sportsmen. This conflict is based on opinion rather than fact.[11] The sportsman thinks all wet lands are unsuited for crop production and are best for wildlife. The farmer thinks all wet lands can be drained and made to produce bumper crops.

Undoubtedly many areas of wet land should be managed to produce wildlife. Examples of such land include areas having shallow peat over sand. This land might be productive of farm crops for a few years, but it would soon become submarginal agricultural land. This is well illustrated in the northern Minnesota and central Wisconsin wet-land areas that were once drained and have now been returned to wildlife production.

On the other hand, there are many wet-land areas that are not wet enough to produce waterfowl, muskrats, or wild rice; yet they are too wet for upland forms of wildlife and for cultivation. Many of these areas could be drained and used to produce farm crops. If that were done and the land well managed, they might even produce more wildlife than they do at present. Examples of such land are the undrained areas of the Clarion-Webster soils in Iowa and Minnesota, the Brookston-Crosby soils in Indiana, Michigan, and Ohio, and the Drummer-Flanagan soils in Illinois.

It is impossible to generalize, as many sportsmen and farmers have done, on the best use to be made of wet land. Each individual area must be judged on its own merits. The major controversy, of course, has always been whether or not wet land should be drained for agricultural purposes.

The answer to the question of whether wet land should be drained depends almost entirely on four considerations: 1. What is the land capable of producing? 2. What effect will drainage have on adjacent lands? 3. What is best for the public interest? 4. Can the land be drained adequately and economically?

In legal drainage districts many of the main and secondary ditches need enlarging and rehabilitating. Outside legal districts, main ditches are needed to provide better outlets for farm drains.

Different methods of drainage are necessary in the various areas of the region. Most of the flat prairie land of the Corn Belt requires systematic drainage, first, by open ditches to remove surface water and provide tile outlets and, second, by tile drains to remove subsurface water. Bedding and drainage terraces are used in the claypan areas of southern Indiana and Illinois, and in northern Missouri. Shallow surface ditches and tile are needed for drainage of depressed or pothole areas. This is typical of the till plains of northern Indiana and southern Michigan and of the area of the Red River Valley in Minnesota. In the Illinois and Mississippi River bottoms there are levee districts with pumping plants. Controlled drainage, by using a system of open ditches and tile and small pumps, is increasing for truck farming of muck lands of Michigan, Ohio, and Indiana.

[11] Anderson, W. L. Wet land—how should it be used? Talk given before 12th North American Wildlife Conference, San Antonio, Texas. February 1947.

In recent years poorer drainage has become noticeable in those areas drained by tile. It is not unusual for the farmer to find it necessary to put in an additional tile. Often he splits his original spacing, which was about 8 rods, and sometimes he even quarters his 8-rod spacings if the land has been used for 40 or 50 years. In all probability, this is due to a breakdown of soil structure. Data from the Northwestern Experiment Station, Holgate, Ohio, indicate that the type of rotation has much to do with the soil structure and with the yields produced. Much can be done to improve drainage conditions by using good rotations.

## SPECIAL PROBLEMS

The cut-over area of Minnesota, Wisconsin, and Michigan offers a special problem. Much of this land is too low in fertility to produce satisfactory crops; yet there is a large population in the cut-over area trying to derive a living from farming. These special problem areas have been recognized by the respective states and by the National Resources Planning Board. Detailed surveys have been made in the sand sections of Wisconsin. Recommendations have been made for certain adjustments, and some progress has been made toward correcting the ill-advised agricultural development that followed the extensive depletion of the forest resources.

The Forest Crop Law of Wisconsin provides tax relief and offers some incentive to protect the timberlands. Many counties have enacted zoning ordinances preventing further settlement in submarginal areas not economically adapted to farming.

Obviously a conservation program in the cut-over areas must consider the social and economic factors as well as the usual soil and water conservation practices.

The following paragraph is quoted from the Wisconsin State Planning Report:

The essentials for the rehabilitation of the region (Lake States cutover area), however, are: (1) the reorganization of its pattern of settlement, so that the farms will be in compact groups located on the best land; (2) an extensive forestry program whose objective is twofold, the restoration of the forests and the provision of employment. Though conditions in the region are not so suitable for agriculture as elsewhere in the state, there are opportunities for the population, and the deficiencies are due quite largely to a shortage in acres of cropland. This is a deficiency which definitely *can be met*, to a considerable degree, if not in full. With a forestry program under way to provide employment, while the farms are in the early stages of development, there is every reason why settlers should become self-supporting.

The above recommendations with sound conservation farm practices should eliminate many of the special problems which now exist in the cut-over area.

# SOIL CONSERVATION AND GOOD LAND USE IN THE WESTERN GULF REGION

## L. P. MERRILL[1]

The Western Gulf Region—comprising Texas, Oklahoma, Arkansas, and Louisiana—includes a varied assortment of physical characteristics which place inexorable limitations upon the use of land.

From the arid western extremes of the region, where rainfall is scant and conservation of water is a major problem, the land's surface drops gradually to the curve of the Atlantic-Gulf Coastal Plain, where productive use of land depends upon the operator's ability to maintain adequate drainage and a good state of soil fertility. In southwest Texas are rugged uplands; in eastern Oklahoma and in Arkansas, mountainous areas. Within the region there are the broad, dry, treeless plains of the western and northwestern areas, the gently rolling hills farther to the east, and the wide stretches of forests, the bottom lands of the Mississippi Valley, the marshlands of the coast, and the near-tropical southern portions of Texas and Louisiana.

The agricultural problems of this 275,730,560-acre expanse are closely related to these factors of physical environment. These factors, of course, have determined largely the distribution of population. They have predetermined, as well, the use that can be made of the land. It has been necessary for man to adapt himself to the limitations of land and climate and to use as efficiently as he might the resources that are available.

Discovery of these use limitations has been preceded at times by costly and destructive practices which have imposed new problems. One of these practices, the plowing of the flat tableland of the High Plains of Texas and Oklahoma without use of measures to control wind erosion, was followed quickly by dust storms, which were physical evidence of the improper use of the land. In the forests of Arkansas, Louisiana, Oklahoma, and Texas, a wasteful harvest of timber from hundreds of thousands of acres has left land exposed to erosion.

On the rangelands misuse has produced another problem. The denuding of grasslands has been followed by invasion of brush and a serious curtailment of the productivity of hundreds of thousands of acres.

By use of irrigation in certain areas in the western and southern parts of the region, man has succeeded in converting arid and semiarid rangeland into intensively productive cropland. And in control of flood conditions and the drainage of lowlands for productive use, much progress is being made.

A handicap in any program aimed at conserving soil and moisture with resulting improvement of land use and agriculture in general is that of farm tenancy and absentee ownership. Since the 1910 census, more than half the farms in the region have been operated by tenants, and this percentage increased until by 1930 the ratio of tenants to owners was nearly two to one. The 1935 census,

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however, showed tenancy to be on the decline in the region, and later counts have indicated an even sharper rate of tenancy decline.

At the same time the number of farm units in the region has been on the downgrade as well. The 1940 census reveals a drop of approximately 15 per cent in the number of farms over the region as a whole. The size of the average farm is shown by the same census to have increased over the 1935 checkup from 176.8 acres to 207.94 acres.

Approximately one tenth of the nation's population resides in the region, and of the 13,564,000 total, approximately one third—5,057,000—live on farms. This farm population ranges from fewer than two persons per square mile in the broad western prairies to more than 33 persons per square mile in some of the areas of eastern Texas and Oklahoma and of eastern Arkansas and Louisiana.

Rainfall ranges from an annual average of 8 to 12 inches in the extreme west to more than 64 inches in some sections of Louisiana. Four broad climatic zones lie across the region from north to south. These are, from west to east, arid, semiarid, subhumid, and humid. These variations in climate have had much to do with the development of the soils, just as they now enforce restrictions upon the agriculture of the region.

Improper land use—overuse by livestock, reckless burning and clean cutting of woodlands, improperly designed mechanical erosion control practices, cropping of steep slopes, and one-crop farming—has resulted in disastrously accelerated erosion. The extent of erosion damage is reflected by the reconnaissance erosion survey of 1934. This showed that 9.1 per cent of the land area of the region was essentially destroyed for further crop use; 9.3 per cent has been affected by severe erosion, and 43.2 per cent by moderate erosion. Approximately 31 per cent of the region has lost little or none of the topsoil. This includes lands needing drainage, nearly level irrigated land, and areas protected with good to excellent cover of grass and timber. Erosion was not recognizable on 7.5 per cent of the land area.

### PRINCIPAL PHYSIOGRAPHIC AREAS AND THEIR PROBLEMS

The region contains parts of six major basic land resource areas: the Atlantic-Gulf Coastal Plain, Appalachian-Ozarkian Highlands, Central Basin, Great Plains, Rocky Mountain Uplift, and Southwestern Mountains and Basins.

Within the Atlantic-Gulf Coastal Plain accelerated water erosion is not a serious problem on the nearly level lands of the coast prairie, bottom lands, loessial terraces, and Gulf Coast marsh. Conservation problems here are the removal of excess surfaces and internal water, improvement of soil structure, conservation crop rotations, and maintenance or improvement of soil productivity.

The Blackland prairies, forested Coastal Plain, loessial hills, and Rio Grande plain, however, present serious water erosion problems. Areas remaining in native cover that have been overgrazed or burned have varying degrees of accelerated erosion. Unprotected sloping lands used for row crops have lost many tons of topsoil.

The Great Plains area includes a vast sweep of plains and prairies lying between the Rocky Mountains on the west and the Central Basin, Appalachian-Ozarkian Highlands, and Atlantic-Gulf Coastal Plain on the east. Surface relief is prevailingly level to undulating and gently rolling over the less-eroded part of the area, undulating to hilly in the wind-blown sandy areas and rough and hilly in the more eroded areas.

## Soil erosion

Accelerated erosion in the Great Plains results from both wind and water. The coarse-textured soils of the area contain little fine material or organic matter and when exposed to winds of high velocities without adequate ground cover, extensive removals and accumulations result. Erosion, here, is serious not only from damage already done, but also because of future damage of much greater proportions that may occur. In addition to the very serious injury to the soil itself, wind erosion has damaged livestock, native pastures, roads, buildings, farm machinery, goods on merchants' shelves, and the general health of the people.

The problem of wind erosion on the High Plains has been developing for more than half a century. The more recent dust storms are the accumulated result of long-continued exploitation, intensified by periodic drought.

Many land units are 160-acre tracts, too small for the support of a family under semiarid conditions. During years of above-normal rainfall, however, crops are profitable. During the highly productive years of World War II the High Plains had sufficient moisture to produce good yields. The dry months of 1946, however, induced conditions which early in 1947 permitted wind erosion damage to cropland that had insufficient cover.

Emergency treatment for controlling wind erosion on the plains includes tillage operations that roughen the surface of the land. Permanent control must include a number of measures: (a) conservation of water; (b) use of protective vegetation such as grass, crops, shrubs, and trees; (c) adaptation of crops and cultural practices to varying topographic, soil, moisture, and seasonal conditions; (d) use of organic residues in a conservation crop rotation; (e) retirement of critically erodible areas to perennial vegetation; (f) a change from cash cropping to livestock operations; (g) proper distribution, timely use, rotation and deferment of grazing on range lands, and adjustment of numbers to grazing capacity.

Among these, crop-residue management has a major rôle in the control of wind erosion. In tillage operations the maximum amount of stubble or crop residue is left on or near the surface to break the force of the wind, increase infiltration of moisture, and retard runoff. This practice also slows down evaporation, making soil moisture available to the plants over a longer period. Records indicate that soil movement is minimized and production is freuqently increased by this practice.

Water erosion is most severe in the eastern part of the area. Thousands of acres of land in the Trinity River watershed have been so severely damaged by sheet and gully erosion that land abandonment is a problem.

Areas have suffered where overgrazing has removed the top growth and allowed the vegetative litter to be lost. These losses show up in reduced vigor of the grasses, reduced amount of better vegetation, and reduced grazing capacity of the ranges.

### Water conservation and control

High on the list of special problems confronting landowners of the Western Gulf Region is that of water conservation. This is just as vital to the areas in the arid and semiarid belts as drainage is to lowland areas of high rainfall.

Slightly more than half the region lies west of the narrow belt in which mean annual precipitation approximates 30 inches and which follows a meandering line south from Kay County in northern Oklahoma to the Gulf of Mexico. West of this belt the soils generally are fertile, but production is frequently reduced by lack of precipitation. East of the 30-inch belt the annual precipitation, if well distributed, usually is adequate for crop production, but yields may be limited by seasonal droughts during the growing season.

In addition to contour cultivation, systems of level, closed-end terraces are used on the permeable soils in the semiarid belt. These mechanical measures are supplemented by the use of conservation crop rotations, stubble mulch tillage, cover crops, and other agronomic practices to increase infiltration and to reduce evaporation by lowering soil temperatures and protecting the soil from the drying action of wind.

The vital necessity of water conservation for successful crop production in an area where the mean annual precipitation is only 20 inches, and falls below 15 inches 2 years out of 5, is strikingly illustrated by an analysis of available precipitation data and wheat yields from 901 farms in the High Plains of Texas, Oklahoma, Kansas, and New Mexico. It was found that terracing with contour cultivation increased the supply of water available to plants by 22 per cent and wheat yields by 60 per cent.

In the uplands of the subhumid and humid portions of the Western Gulf Region, terraces are built with a variable grade, not exceeding 3 inches in 100 feet near the outlet end, and crop rows parallel the terraces. The primary function of the terraces is erosion control, but they also retard runoff. Terraced land produced 33 per cent more cotton and 14 per cent more corn than unterraced land on a number of farms studied in the Elm Creek watershed near Temple, Texas, from 1936 through 1939.

*Farm ponds.* Farm ponds are used for livestock water supply throughout the region. In the arid and semiarid areas ponds must be large and relatively deep to be dependable. Capacities commonly range from several acre-feet to tens of acre-feet. As many as 100 to 150 animal units may water from one pond. From 12 to 30 months may elapse between storms which produce enough runoff to refill the pond, and the annual evaporation loss may be as much as 6 or 7 feet.

It is probable that there are at least 250,000 farm ponds which are used for livestock water supply in the four states, with an aggregate capacity of perhaps 500,000 acre-feet.

The production of fish as a source of food and recreation for farmers and ranchers has proved a popular use for farm ponds and stock-watering tanks.

A relatively small number of farm ponds supply irrigation to farm gardens or trucks crops. Irrigation from ponds has increased recently and there is justification for a much greater use of ponds for supplemental irrigation of gardens and truck crops.

*Irrigation.* The major irrigated areas in this region are in Texas and Louisiana. Rice is the predominant irrigated crop grown in Arkansas. The largest irrigated area is in the Loessial Terrace area east of Pine Bluff. Additional areas were developed recently in the eastern part of the state. Nearly all irrigation is provided by pumping from wells, and the most serious problem is that of declining ground water levels. The market value of rice determines whether pumping lifts are profitable. A partial solution to this problem will be the diversion of water from the White and Arkansas Rivers. A plan for such diversion is now under study by the U. S. Corps of Engineers.

In Louisiana, irrigation is confined almost entirely to rice, grown in the Coast Prairie lying along the Gulf of Mexico west of the Mississippi River. Some of this area is irrigated by pumping from wells, but the major source of irrigation water is diversion from streams, both by gravity and by pumping. The lower part of the rice-growing area is sometimes seriously affected by intrusion of salt water from the Gulf of Mexico during periods of low stream flow.

The irrigated areas in Oklahoma are small and scattered widely throughout the western part of the state. Most of the water for irrigation is diverted or pumped from streams, but some well irrigation is practiced, particularly in the three Panhandle counties. The largest irrigation development in the state, near Altus, is expected, eventually, to cover some 30,000 acres.

During recent years the High Plains of Texas have become the major irrigated area of the state. It is estimated that during 1946 at least 650,000 acres were irrigated from approximately 5,500 wells. Unprecedented increase in well irrigation is shown by the fact that in 1936 only 600 wells were being pumped to irrigate 80,000 acres. Records of water level measurements made during the last decade show that more than 80 per cent of the water now being pumped represents withdrawal from storage and that storage depletion amounted to more than a million acre-feet during the 3-year period 1943 to 1946.

Approximately 350,000 acres of land are irrigated in the Lower Rio Grande Valley in Cameron, Hidalgo, and Willacy Counties. The major crops are citrus fruits and vegetables; appreciable areas of alfalfa, cotton, and miscellaneous crops are also irrigated. Nearly all the irrigation water is obtained by pumping from the Rio Grande, except for small quantities pumped from natural lakes formed in old river channels. Because of low flows in the Rio Grande during the summer months, water shortages are experienced almost annually. It is hoped that the proposed construction of an international dam on the Rio Grande will assure sufficient water to the present irrigated area and bring an additional 350,000 acres under irrigation.

About 300,000 acres of rice are irrigated annually throughout the Coast Prairie

area along the Gulf of Mexico in Texas. Most of the irrigation water is obtained from streams or fresh water lakes by gravity diversion and pumping.

Other major irrigation areas in Texas include the Rio Grande Valley near El Paso, Texas, which receives its water supply from the Elephant Butte Reservoir in New Mexico, the Pecos River Valley near Pecos, Texas, which is irrigated from the Red Bluff Reservoir on the Pecos River near the New Mexico line, and the pump irrigation area in the Winter Garden district southwest of San Antonio. The problem of excessive salinity is particularly serious in the Pecos River Valley.

*Drainage problems.* Drainage is a major agricultural problem in three general types of areas in this region. These are, first, the Coast Prairie in Louisiana and Texas along the Gulf of Mexico; second, the alluvial lands of the Mississippi, Arkansas, and Red Rivers and other major streams; and third, irrigated areas. Except in the irrigated areas, adequate drainage ordinarily can be provided by open ditch systems.

TABLE 1

*Drainage needs in the Western Gulf Region*

| STATE | MAJOR DRAINAGE PROBLEM AREA | DRAINAGE ENTERPRISES* | | ADDITIONAL AREA FEASIBLE FOR DRAINAGE | TOTAL AREA NEEDING DRAINAGE IMPROVEMENT |
|---|---|---|---|---|---|
| | | Number | Drained area | | |
| | *acres* | | *acres* | *acres* | *acres* |
| Arkansas............... | 11,626,000 | 287 | 4,136,000 | 1,434,000 | 5,570,000 |
| Louisiana............... | 18,071,000 | 511 | 3,173,000 | 3,597,000 | 6,770,000 |
| Oklahoma.............. | 810,000 | 29 | 181,000 | 69,000 | 250,000 |
| Texas.................. | 13,500,000 | 91 | 2,813,000 | 4,372,000 | 7,185,000 |
| Total................ | 44,007,000 | 918 | 10,303,000 | 9,472,000 | 19,775,000 |

\* Data from U. S. Census, 1940.

A survey to determine the location and extent of major surface drainage problem areas in this region was completed in November 1945. The needs as determined by this survey are summarized in table 1.

In determining the drainage needs it was necessary to eliminate 3,052,000 acres that have sufficient slope or good internal drainage and also 5,148,000 acres of treeless open marsh in Louisiana and Texas adjacent to the Gulf of Mexico, which, except for some small areas, is considered unsuited at present for agricultural drainage.

An additional 18,202,000 acres are not considered feasible for drainage for reasons other than soil characteristics, such as frequency or duration of overflows or elevation in relation to existing outlets. It is safe to assume that at least three fourths of the total job of providing outlets for drainage water from nearly 20 million acres of land remains to be done.

Farmers cooperating with soil conservation districts have provided surface drainage for 192,346 acres of land. This is less than 1 per cent of the area needing drainage.

The two major irrigated areas in which drainage is a serious problem are those along the Rio Grande near El Paso, Texas, and in the Lower Rio Grande Valley. Subsurface drainage is needed to keep the ground water table at a sufficient depth below the surface of the land to prevent damage to field crops and orchards.

*Flood control.* This region has extremely high intensities of rainfall, both during local thunderstorms and in storms of several days' duration that cover thousands of square miles and produce major floods on most of the large rivers at less than 5-year intervals. Rains of extreme intensity occur more frequently in the Balcones Fault area of south-central Texas than in any other area of similar size in the United States. It is estimated that during the last 55 years, floods in Texas have caused damage in excess of $180,000,000 and have resulted in the loss of more than 1,100 lives.

Preliminary flood control surveys have been completed in the watersheds of the Trinity and Middle Colorado Rivers in Texas and the Washita River in Oklahoma. Watershed treatment programs authorized by Congress are now in progress in those areas.

These surveys have shown that in the portions of the watershed which will not be protected by reservoirs, as high as 95 per cent of all damage caused by flood waters is agricultural. Furthermore, studies of typical tributaries of the Trinity and Washita Rivers indicate that 75 per cent of all flood water damage is caused by floods which occur more often than once in 5 years and that 30 to 40 per cent of such damage is caused by floods occurring once or more each year.

Programs in aid of flood control include three general types of measures: first, land treatment to minimize erosion and runoff; second, small detention reservoirs on minor tributaries to reduce the frequency and severity of flooding; third, improvement of headwater stream channels to increase their capacity.

Most of the land treatment measures will be applied by individual farmers, with technical assistance from soil conservation districts.

*Sedimentation.* Since surface water supplies are a vital resource in the economy of this region, reconnaissance measurements of sedimentation have been made on 103 reservoirs and detailed surveys have been completed on 26 others. Some studies of accelerated sedimentation damages in channels and floodways have been made in the watersheds of the Grand Neosho, Lower Arkansas, Red, San Jacinto, Trinity, and Middle Colorado Rivers.

There is a wide range in rates of sediment production and damage by accelerated deposition throughout this region. The lowest rates occur in the Ozark and Ouachita Highlands of Arkansas where forest cover, thin soils, and hard underlying rock formations limit the sediment output to an average of approximately 0.5 acre-foot annually per square mile of drainage area. Properly designed reservoirs in these areas may have useful life expectancies of several hundred years. Damages to valley lands by sedimentation are limited to local areas. In the Rolling Red Plains, Blackland Prairies, Cross Timbers, and parts of the Forested Coastal Plain, however, severe and spectacular erosion has caused major damages to large areas.

## PROGRESS IN SOIL CONSERVATION

In the sandy soils of the western parts of the region and in all soils of the eastern portions, rapid decomposition of organic matter and loss of available plant food through leaching, oxidation, and erosion have thrust upon soil conservation forces a most acute problem.

A conservation cropping system which includes cover and soil-improving crops, proper management of crop residues, and strip cropping is of major importance in minimizing soil losses and in helping to maintain and even increase soil productivity.

Conservation cropping systems now used within the region include annual and perennial legumes and grasses in combination with clean-tilled or row crops. The legumes and grasses, planted broadcast or in close-drilled rows, provide protection against soil erosion and add organic matter to the soil.

The introduction of Hubam clover as an effective legume for Blackland soils has been a boon to the agriculture of the area, and in its wider acceptance the Soil Conservation Service and soil conservation districts have played a large part. Because of root rot, no summer legume, until the introduction of Hubam clover, had been found to furnish cover protection while serving also as a soil-improving agent. The use of Hubam spread quickly over the area, and reports of improved yields following this clover have been impressive. Wheat yields for some operators have doubled. Hubam provides excellent hay and forage. Since it is easily combined, farmers can harvest their own seed.

Peanuts are one of the major cash crops of the Cross Timber area. Harvesting both vines and nuts leaves nothing on the surface to protect the land from wind and water erosion during winter and spring. The need for protection was met most effectively with the introduction of hairy vetch to the Cross Timbers. While protecting the soil, it is effective, too, as a green manure, soil-improving crop, for forage, and, grown for seed, it has paid operators well. Following vetch, peanut yields have increased as much as 20 bushels per acre, and oats, as much as 45 bushels.

### Conservation crop rotations

A conservation crop rotation which has proved effective in conserving the soil and increasing its productivity in the rolling, sandy land area of eastern Texas, Louisiana, southern Arkansas, and southeastern Oklahoma, is:

First year—corn and summer legumes, followed by vetch or other winter legume in fall, worked into the soil in spring;

Second year—cotton, followed by small grain in fall;

Third year—cowpeas or other summer legume, with crop residue left on the surface or worked into the soil.

Such a cropping system is a great improvement over that of alternate cotton and corn, or straight cotton, which leads to soil loss and soil depletion. When organic matter is depleted, not only does production decrease, but the soil erodes more rapidly.

PLATE 6. FARM BOUNDARIES DO NOT BREAK THE PATTERN OF SOIL-CONSERVING PRACTICES IN THE CENTRAL TEXAS SOIL CON-SERVATION DISTRICT WHERE NEIGHBORS EXTEND THEIR CONTOURING, TERRACING, AND STRIP CROPPING FROM FARM TO FARM

Use of a conservation crop rotation, in combination with contour tillage, terracing, and proper use of crop residue, results in 30 to 50 per cent increase in crop yields.

Satisfactory growth of cover and soil-improving crops, as well as cash crops, depends to a large degree on application of the necessary soil amendments—potash, phosphorus, nitrogen, and lime. Soils that have been cultivated for any time in the high rainfall area are usually deficient in one or all of these elements.

A rotation of cotton, wheat, and sweet clover over a 15-year period at the Soil Conservation Experiment Station at Guthrie, Oklahoma, reduced soil losses 75 per cent and water losses 25 per cent over a 5-year period; in the same rotation, the yield of cotton was increased 87 pounds per acre.

Alfalfa, annual lespedezas, kudzu, crotalaria, sweet clover, bur clover, crimson clover, cowpeas, soybeans, lespedeza sericea, Austrian winter peas, vetches, and lupines are all important components of conservation crop rotations in various parts of the region. Small grains, sorghums, and sudan, annual and perennial grasses all play an important rôle in the conservation cropping systems.

### Stubble-mulch farming

Stubble-mulch farming is practiced extensively in the western part of the region. Four years of records (1943-1946) at the Amarillo, Texas, Conservation Experiment Station show that stubble-mulch treatments, in comparison with plowing and disking, increase wheat yields and leave the soil surface protected from wind erosion. The average yield from stubble-mulched areas was 11.4 bushels per acre compared to 8.6 bushels from plowing and disking methods, a 25 per cent increase in grain yield.

Strip cropping is important in areas subject to wind erosion. Its use with cover crops constitutes a major phase of the soil conservation program in the Cross Timber and other areas subject to wind erosion.

The planting of four to eight rows of peanuts following a cover and green manure crop in a strip cropping pattern with crotalaria, grain sorghum, or other tall-growing crops provides protection against wind and water erosion. Alternating the crops in the strips from year to year provides a sound conservation cropping system. The residue from the strips is left on the land or worked into the soil, supplying needed organic matter and essential elements.

### THE RANGE LANDS

Over 75 per cent of the native ranges of the Western Gulf Region have lost more than 50 per cent of the original plants that were dominant on the primitive grasslands. Productivity, or beef-making power, has dwindled correspondingly. The stockman's eye has been for his livestock and not for his grass, hence the grass gave out under the cattle and sheep without his realizing it until weedy grasses and forbs and unpalatable woody vegetation had taken possession of much of the land.

### Range land management

Encouraging progress in this region is being made in range land management. Livestockmen generally are recognizing the cost of too heavy stocking of range

land, and in many sections they are welcoming aid in the installation of conservation programs. There are now enough instances of proper management of grasslands to prove that rotation grazing, an adjusted stocking rate, water conservation, and other practices in the program can pay dividends in weights, quality, and rate of reproduction of livestock.

Comparisons of rainfall penetration rates for ranges in good and poor condition furnish convincing support for proper stocking rates in the drier areas of the region. These studies show that soil in the Concho River Basin, Texas, absorbed an average of 1.17 inches of rainfall per hour where the range cover was in good condition as against 0.15 inch per hour for the same soil on range in poor condition.

Closely related to the problem of range management is that of brush eradication. Mesquite, limited to "islands" in Texas in the days of Spanish occupation, has spread until now 33 million acres of land in Texas are heavily infested and 22 million acres are lightly infested. Heavy use of range lands in livestock production is certainly a contributing factor in the rapid spread of undesirable brush and trees. Land covered by woody vegetation cannot produce good yields of grass. Eradication of mesquite, cedar, and chapparal is receiving much attention in the region. Experiments show that rootcutters, treedozers, saws, and chemical solutions can be effective.

### Revegetation of the range

Use of native plants for revegetation and development of efficient equipment for harvesting and seeding native grasses are contributing materially to the progress of range conservation.

The need for reseeding eroded grasslands and croplands presented another problem of the conservation program. To return hundreds of thousands of acres to economic use, native grass seed adapted to the soil and climate and desirable as stock feed is essential. There was no such seed on commercial markets. It could be obtained only from wild native stands. In lieu of sufficient native grass seed, introduced grasses were tested. Within a 10-year period Bermuda grass, for example, proved its value and is now accepted and used wherever adapted in the region. Harvesting techniques had to be learned, and harvesting and planting equipment had to be devised. But there is still a shortage of seed and suitable planting equipment, while the demand from landowners is constantly growing.

Bermuda, dallis, and carpet grass, clovers, and annual lespedeza are used in the development of improved permanent pastures, and kudzu and lespedeza sericea are used for meadow and supplemental grazing in the eastern part of the region.

The Soil Conservation Service personnel of the region have successfully developed suitable planting equipment. Most of this still has to be made to order, but many individuals and soil conservation districts have acquired it and the demand is growing.

Important native grasses used in revegetation work in the western and southwestern parts of the region are blue grama, sideoats grama, slender grama,

buffalograss, bluestems, switch grass, Indian grass, sand lovegrass and western wheatgrass. Introduced grasses used are weeping, Lehmann, and Boer lovegrasses, crested wheatgrass, and Rhodes grass.

The value of reseeding and reforesting wornout land is being proved on the 376,074 acres in land utilization projects in the region. Reseeding or reforestation of the eroded areas has progressed rapidly. Some of these are now yielding economic return again through timber harvesting and leasing for livestock grazing.

### Woodlands and windbreaks

In large areas of the Western Gulf Region timber production is a leading industry. Southern pines are the principal commercial trees in the uplands of the coastal plains, although there is an almost equal quantity of low-grade hardwood mixed with the pine. A variety of valuable hardwoods occupy extensive areas of bottom land and terraces along the major rivers. The oak-hickory type dominates the Ozark Highlands. There are great areas of scrub post oak-blackjack oak-hickory to the west in the mountain region.

In large cut-over areas and in some severely eroded areas reforestation is the most practical conservation treatment. Estimates indicate that 17 million seedlings are needed annually for such a reforestation program in the region. Management of existing woodlands, including selective cutting and control of burning and grazing, is gaining more widespread acceptance as district cooperators begin to reap benefits from the practice.

Establishment of windbreaks in the Rolling Red Plains areas of Texas and Oklahoma has been effective where soil and moisture conditions are favorable. Such protection is effective on land surfaces up to about 20 times the tree heights on the light-textured soils on which crops are subject to damage from wind by erosion, sand blasting, and excessive moisture evaporation.

Varieties of trees used most frequently in windbreaks are Chinese elm, poplar, sycamore, honey locust, red cedar, Russian mulberry, and apricot. Investigations show that suitability of site for windbreaks in the Plains areas depends on continuous moisture during the growing season.

#### SOIL CONSERVATION DISTRICTS

The problems of the Western Gulf Region are being analyzed by science, and they are being solved by cooperation of owners and operators, united in soil conservation districts. By means of these districts farmers and ranchers are able to use more effectively the services of federal, state, and other agencies.

In many areas the program of soil conservation has been most capably carried on by boards of supervisors of soil conservation districts working with groups of land operators. These districts have combined democratic principles with scientific investigation and education in protecting the soils and increasing the yields and income from the farms and ranches of this region.

A summary of farmer opinion in 1944 on 3,800 farms and ranches in the region indicated that yields increased an average of 32 per cent on crop, pasture, and

range land where soil conservation practices had been in effect for 2 or more years.

In the four states of the region there are 296 districts covering 221,414,700 acres, or 80 per cent of the land area. Of this total, 246 districts are receiving assistance from the Soil Conservation Service in planning, applying, and maintaining conservation practices. These cover 184,714,800 acres. Other districts, more recently formed, soon will be ready to make use of such assistance.

A total of 28,507,006 acres are under conservation plan in active form. Of this total the equivalent of 12,779,627 acres have received treatment. There are 608,660 operating units, farms and ranches, in the area covered by districts. These units embrace 133,279,506 acres.

Although the extent of district organization indicates progress, the development of the district program is only just beginning to bear fruit.

# SOIL CONSERVATION AND GOOD LAND USE IN
## THE NORTHERN GREAT PLAINS REGION

### A. E. McCLYMONDS[1]

Geographically, the Northern Great Plains is a sizeable empire made up of the states of Montana, Wyoming, North Dakota, South Dakota, Nebraska, and Kansas. This is an area of 351,474,560 acres, or 18 per cent of the land in the United States. It extends 825 miles from north to south, 876 miles from east to west at its widest part, and 1,350 miles from southeast to northwest. In addition to vast national forests, parks, and other federal and state lands, it contains 24 per cent of the total land in farms in the United States. Forty per cent of the land in farms is cultivated.

Only 4 per cent of the people in the United States live in this region, but from it many peoples get a substantial part of their basic foodstuffs.

According to the 1945 agricultural census, with only 7.5 per cent of the farms and 6.1 per cent of the farm population of the nation, the region in 1944 produced 43 per cent of the wheat, 46 per cent of the barley, 42 per cent of the sorghums, 37 per cent of the rye, 28 per cent of the flax seed, 20 per cent of the sugar beets, 19 per cent of the alfalfa hay, 16 per cent of the oats, and 17 per cent of the corn. In all, the region produced for sale 11 per cent of the total value of all crops sold in the nation. It also produced for sale 17 per cent of the nation's cattle, 20 per cent of all the pork, 26 per cent of the lamb and mutton, 23 per cent of the shorn wool, 9 per cent of the milk, 17 per cent of the creamery butter, and more than 10 per cent of the chickens, turkeys, and eggs.

The conservation job for the Northern Great Plains is complicated by a diversity of problems. Corrective measures must take into consideration the use and management of irrigated land, dry-farming land, and extensive areas of range and timberland. Accomplishments have been most effective where individual effort has been coordinated and guided through cooperation with soil conservation districts aided by the technical standards developed by the technical staff of the Soil Conservation Service and with the assistance of other public agencies. Ultimate solution depends upon a full appreciation of the problems by land operators and the public and upon their willingness to proceed aggressively with individual and group adjustments.

### DESCRIPTION OF THE REGION

The region embraces parts of three broad physiographic areas:

1. The Central Basin consists of a small area in southeastern South Dakota, the eastern border of Nebraska, and the eastern third of Kansas.
2. The Rocky Mountain Uplift consists of the mountainous western third of Montana and the western two-thirds of Wyoming.
3. The Northern Great Plains area consists of the bulk of the six states in the region, that is, all of Montana and Wyoming east of the Rocky Mountains, all of North and South

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[1] Regional Conservator, Soil Conservation Service.

Dakota except the extreme southeastern corner of South Dakota, the western four-fifths of Nebraska, and the western two-thirds of Kansas.

Most soils in the region developed under grassland, except for the Rocky Mountain forest land. Great soil groups that occupy various natural landscapes include the prairie soils in eastern Kansas and Nebraska and extreme southeastern South Dakota; the chernozem soils in a zone that extends from eastern North and South Dakota through central Nebraska and Kansas; the chestnut soils in northern Montana, western North and South Dakota and Nebraska, and northwestern Kansas; the reddish chestnut soils in south-central Kansas; the brown soils in southwestern Kansas, eastern Montana, and Wyoming; and the sierozem soils in the intermountain basin and high dry plateaus in western Wyoming.

Elevations rise from east to west. The lowest elevations are in southeastern Kansas (750 feet) and in northeastern North Dakota (789 feet). The highest is Gannett Peak, 13,785 feet, in Wyoming. The valley elevations in the Rocky Mountain Uplift range from approximately 7,000 feet in the high mountain valleys of Wyoming to 1,800 feet in northwestern Montana.

Average annual rainfall ranges from 8 inches in southwestern Wyoming to 45 inches in southeastern Kansas. Outside the western mountainous area, about 70 per cent of the normal rainfall occurs during the growing season. Because of the torrential type of rains, flash runoff is common.

The intensity of wind movement is highly variable and may reach high velocities at critical periods in spring and fall. On the High Plains, velocities of short duration up to 100 miles an hour have been recorded. Fifty-mile-an-hour winds are not uncommon.

More than four fifths of the region is in the Missouri River drainage basin. Northern and eastern North Dakota are in the Hudson Bay drainage basin, southern Kansas is in the Arkansas River basin, southwestern Wyoming is in the Colorado River basin, and northwestern Wyoming and western Montana are in the Columbia River basin.

Population is concentrated in the southeastern part of the region. Nearly 36 per cent of the people live in the eastern third of Nebraska and Kansas, which is only 8 per cent of the area of the region. More than half of the population is in the eastern 17 per cent of the region. Elsewhere, agricultural population is relatively sparse, except in irrigated areas.

### PRIMARY AGRICULTURAL AREAS

There are five primary agricultural areas in the region: spring wheat area; corn, small grain, and livestock area; winter wheat area; Northern Plains range land; and Rocky Mountain range and forest area.

The spring wheat area consists of northeastern Montana, all of North Dakota, and northeastern South Dakota. It is an area of broad expanses of nearly level and undulating topography with hilly grasslands in places. Average annual rainfall ranges from 16 to 24 inches northwest to southeast, and growing seasons range from 103 to 130 days north to south. Wheat is the major crop, with barley and oats next in importance. Flax and corn are also grown. Livestock

production is general, and in the eastern part of the area dairy products yield substantial farm income.

The corn, small grain, and livestock area includes southeastern South Dakota, the eastern half of Nebraska, and the eastern third of Kansas. It is the most humid part of the region. This area comprises nearly level and gently rolling land in southeastern South Dakota, central Nebraska, and parts of eastern Kansas, and the rolling to hilly land adjacent to the Missouri River in eastern Nebraska and northeastern Kansas. The rainfall ranges from 22 inches in the north and west to 45 inches in the southeast. The growing season is from 122 days in the north to 200 days in the south. Corn is the important crop. Wheat, oats, alfalfa, and sweetclover are also important. Soybeans, flax, and sorghums are grown. This is the major dairying area and feedlot of the region.

The winter wheat area comprises the western two-thirds of Kansas and western Nebraska. Winter wheat is also grown in north-central Montana. The topography for the most part is nearly level except adjacent to drainages. Average rainfall is from 16 to 33 inches, and the growing season is from 145 to 190 days. Winter wheat is the most important crop. Grain, forage sorghums, broom corn, some corn, and alfalfa are grown.

The Northern Plains range land consists of Montana and Wyoming east of the Rocky Mountains and of western South Dakota and northwestern Nebraska. Within this vast area are relatively small areas of nearly level, cultivated land. The range land consists of sand hills, badlands, small hilly to mountainous areas, buttes, mountain foothills, and nearly level table land. The average annual rainfall is from 12 to 20 inches, and the growing season is from 100 to 120 days. Livestock grazing and feed production are the principal land uses. In local areas wheat is an important crop.

The Rocky Mountain range and forest area consists of rugged mountains, high plateaus, and mountain valleys, chiefly in western Montana and Wyoming, and the Black Hills of western South Dakota and northeastern Wyoming. It is suited primarily for forest, with limited summer grazing. Many of the valleys are irrigated for supplemental feed production and some of the larger are irrigated for the production of sugar beets, beans, alfalfa, and small grains.

## CONSERVATION PROBLEMS

The Northern Great Plains Region is the transition area east to west from the more humid, longer growing season of the Mississippi Valley to the drier and shorter growing season of the Great Plains. Conservation problems in this region are tied particularly closely to the behavior of a widely varying and highly erratic climate and its relationship to the types of agriculture practiced on the land. Weather records show, for example, that the 20-inch rainfall line which normally lies in central Nebraska may move eastward almost to the eastern border of Nebraska and Kansas in dry periods. In wet periods this line may move westward almost to the eastern border of Montana and Wyoming. This creates a zone about 300 miles wide where precipitation is unpredictable and ranges from

an amount less than enough to produce average crops to an amount capable of producing bumper yields.

Homestead laws setting up small units contributed to the misuse of land. This situation has by no means been fully corrected, but the size of units has increased over the years. Census data indicate that the average size of farms increased from 310 acres in 1900 to 616 acres in 1945. Generally the size of units is larger as the precipitation decreases, except in irrigated areas. Successful units range upward in size from 100 acres in the irrigated area and 200 acres in the humid areas. In the wheat belt, units range from 600 to 1,000 acres. In the range area ranches of 50,000 acres are not uncommon. In the western semiarid part most units depend on irrigated land for their winter feed base.

The present ownership pattern of rectangular units that developed because of the laws governing land surveys has influenced field boundaries. Small tracts of good land intermingled with poor land are farmed in one block. Much can be done toward correcting misuse of small tracts through rearrangements of field boundaries within existing units.

Demands of absentee owners for crop production are still a limiting factor to good land management of many farms. Census figures show that 40 per cent of the farms were operated by tenants in 1930, 45 per cent in 1935, and 36 per cent in 1945. Closely connected with the tenancy situation, speculative farming presents a difficult problem, especially in the wheat areas. The average non-owner-operator farms large tracts of land during periods of favorable weather and prices with little regard to necessary conservation practices; and in periods of extended drouth he ordinarily fails to assume his responsibility to the land. This is often the starting point for a large-scale wind erosion problem.

The conservation needs survey made by the Soil Conservation Service showed that there are $11\frac{1}{2}$ million acres now in cultivation that are suitable only for grass or woodland. There are, however, 20 million acres of land capable of producing cultivated crops now in grass or trees that can be cropped if they are needed. These areas occur as small parts of farm units throughout the area.

In the last 10 years, $4\frac{1}{2}$ million acres of land in the Northern Great Plains have been seeded to perennial grasses. Surveys indicate that another $11\frac{1}{2}$ million acres should be seeded. This is one of the primary agronomic problems, but in addition the need for maintaining soil fertility by use of soil-conserving crop rotations and the need for establishing vegetative water-disposal systems are great. Noxious-weed control, contour farming, contour strip cropping and management of crop residues to prevent soil loss are basic problems throughout the area. Good crop production practices such as the use of adapted crop varieties, timeliness of tillage, and proper rate, date, and method of seeding also have great significance in attaining maximum crop production and conservation benefits.

During the last few years of higher agricultural income, farmers and ranchers have applied many mechanical conservation measures that require cash outlay, such as land leveling, irrigation structures, dams, terraces, grassed waterways, diversions, drainage, and windbreaks. On the other hand, patriotic efforts for high production, and also the opportunity for higher per-acre income, brought

an increase in soil-depleting crops such as corn, soybeans, flax, wheat, and potatoes. Several million acres of sod land were also broken for production of war crops.

*Soil erosion*

*Cultivated land (nonirrigated)*. Erosion and land deterioration are most serious in the wheat and corn areas. Effects of wind and water as erosion agents vary throughout the region because of the wide range in amounts and intensity of rainfall. Water is the principal erosion agent in the corn, small grain, and livestock area. Elsewhere, both wind erosion and water erosion are active, with wind erosion increasing in importance over water erosion from east to west as the annual rainfall decreases. Both sheet erosion and gully erosion are serious in southeastern South Dakota and in eastern Nebraska and Kansas. In the more intensive water erosion areas, the loss of topsoil and severe gullying are gradually causing abandonment or a shift from straight cash-crop farming to livestock-grass farming. Water erosion has also increased bridge and road maintenance expenses tremendously.

The semiarid Red Desert in southwestern Wyoming is subject to wind and water erosion because of high winds, torrential rains, and sparse vegetation.

Control of water erosion requires the return to permanent vegetation of land not suited for cultivation; maintaining plant residues on the surface; necessary mechanical measures and vegetative protection to distribute and dispose of excess water to prevent detachment and transportation of soil particles; crop rotations to maintain a desirable supply of plant nutrients; and use of commercial fertilizers and soil amendments as needed.

Wind erosion is dominant in the less humid parts of the region. These include western Kansas, Nebraska, North Dakota, South Dakota, and north-central Montana. The wind erosion hazard is especially severe in southwestern Kansas and on light-textured soils used for cultivated crops. Land not suited for cultivation may deteriorate even below profitable range production as a result of cultivation. An estimate by the Soil Conservation Service, Office of Research, was that during the '30's in southwestern Kansas about 60 per cent of the dust came from cropland unsuited for cultivation, only 5 per cent from good land poorly farmed, and 35 per cent from fairly good land that could have been farmed successfully by using proper wind erosion control methods.

The effects of wind erosion to date have not been definitely evaluated in terms of long-time productivity. Many of the better lands that were wind-eroded have produced good crops during the recent favorable climatic periods. As yet, the lack of moisture appears to be the limiting factor in crop production. If further wind erosion proceeds to the point that soil rather than moisture becomes the limiting factor and the organic matter is depleted and soil structure destroyed, the land will cease to be cropped.

The most pressing problem in the wind erosion areas is to conserve and store more of the rainfall in the soil.

Control of wind erosion requires leveling hummocks on eroded areas; retiring

from cultivation and seeding to perennial grasses light-textured and predominantly sandy land; tilling the soil to leave the residues on or near the surface of the soil; conserving crop residues by prevention of burning and over-utilization by livestock; mechanical measures such as contour farming, timely tillage, and terracing to increase the storage of rainfall in the soil; systematic crop rotations that leave the soil protected as much of the time as possible and include grass in the rotation once each 15 years; wind strip cropping on strips from 5 to 20 rods wide, alternating row crops, or following with close-growing crops; field shelterbelts on suitable soil; and stubble-mulch tillage on fallowed land. In some areas special practices are needed, such as emergency tillage, buffer strips of grass or tall-growing crops, and winter cover crops in adapted areas. Small blown-out spots should be covered with barnyard manure, straw, or hay mulch. Badly eroded fields need emergency cover crops of sudan or cane or small grain.

*Pasture, range, and forest lands.* About two-thirds of the region is native pasture, range, and forest lands. Much of the forested area is used for grazing. Tame-grass pastures and native haylands make up only a small percentage of the total grassland. Destruction of vegetative cover by overuse is the principal cause of erosion and soil decline on range land. Drouth periods do not usually cause serious erosion unless coupled with excessive grazing. In eastern Kansas and Nebraska, overgrazing, not drouth, is the common cause for range and pasture deterioration.

In northeastern South Dakota, northeastern Montana, and North Dakota, concentration of livestock in small pastures is largely responsible for the erosion that has occurred. Generally the grassland in this area is the least eroded of any in the region.

Erosion on the steep slopes along the Missouri River in Nebraska and the claypan soils of southeastern Kansas is serious. Pastures are small, frequently on steep slopes and highly erodible soil, and rainfall is high and often torrential. Runoff from plowed land above creates serious erosion and siltation problems on pastures. The invasion of undesirable plants as a result of heavy grazing has decreased forage production.

Virtually none of the range in western Kansas and southwestern Nebraska is considered in excellent condition. Two thirds is only fair. In this area reduction of the vegetative cover causes a wind erosion hazard. Contour furrows on some of the medium-textured to moderately heavy soils are an effective control measure. On sandy soils emergency treatments include listing and planting a cover crop, and on dune sand, listing and covering blow-out spots with hay or straw mulch. A vegetative cover must be re-established. Deposition of a thin layer of dust on range land renders the soil temporarily impervious and smothers grass plants. Pastures with accumulations of drifted soil recuperate, but it may take several years unless hastened by renovation or reseeding.

The Northern Plains range land has the largest acreage of grassland; 13 per cent is in excellent condition and 40 per cent good. Except for the Nebraska Sand Hills, vegetation of this vast area is short grass or mixed prairie type. The principal cause of soil erosion is overuse by livestock, coupled with dry periods.

PLATE 7. CONTOUR CROPPING AND WIND-STRIP CROPPING ARE PART OF THE PROTECTION OF CROPLAND FROM WIND EROSION IN WESTERN NEBRASKA

In the foreground is a water-spreading system in a pasture, designed to make use of part of the runoff from Wildcat Ridge, from which the picture was taken. The drainageway starts at the bottom of the picture and leads to a dam, which holds back part of the water. Below the dam is the water-spreading system into which water is released under control. The added moisture thus supplied increases the production of grass materially.

Steep hills and canyon sides bordering streams afford shelter to livestock and are close to water. They are covered with relatively sparse vegetation, and washing and cutting beyond the normal amount is easily induced by overgrazing. The effects of loss of vegetation, however, have been more significant than loss of soil. During the last few years of above-normal rainfall, nearly all the native grasslands have recovered to some degree, most of them completely.

The Nebraska Sand Hills is a very deep sand dune formation, steeply rolling with broad well-watered valleys and occasional lakes. Dominant vegetation is tall and mid grasses. Virtually all is used for grazing livestock, mostly cattle. The valleys produce native hay. The area suffers less from drouth because of little runoff, owing to rapid infiltration of the sandy soils. Wind movement of the sand is a constant threat, however, and cultivation and overgrazing have such disastrous results that they are rarely encountered.

Approximately 68 per cent of the Rocky Mountain and forest area is classed as range and 30 per cent as forest. Much of the range supports sparse tree growth, and some of the forested area is grazed during summer. Erosion here can be attributed to overgrazing of livestock and to logging. Grazing lands on the western slope in Montana and Wyoming support bunchgrasses and other herbaceous plants of the Palouse type. Through overuse, the original vegetation has been replaced partly by annual grasses and weeds. The long, steep slopes lose soil rapidly, small valleys and canyon bottoms are gullied, and damaging silt loads are deposited on the more level and productive land. Remedial measures are protection, reseeding, and adjustments in land use. The economy is based on livestock raising, wood products, and recreation. Vegetation in Wyoming's Red Desert is salt desert shrub and sagebrush. The economy is based entirely on livestock and irrigation farming. Much of the grazing land is used as winter range for sheep.

*Irrigated land.* It is generally conceded that the semiarid Northern Great Plains will not support a permanent agriculture unless supplemented by irrigation. The application of irrigation water changes the type of agriculture to one essentially the same as that practiced in the subhumid and humid regions to the east. Irrigated land is subject to both water and wind erosion of a severity depending on the soil, slope, method of applying water, tillage methods, and crop. Wind erosion is serious wherever clean-tilled crops such as beans, potatoes, and beets are produced. Flash floods from adjacent unprotected sloping land also cause severe damage to irrigation systems and irrigated land.

The irrigated lands are in compact areas adjacent to the major streams. The water supply for irrigated land is obtained by direct diversion or storage from the surface flow of streams and from underground sources. Though most of the irrigated land receives its supply from surface runoff, underground water is used extensively in the Platte and Republican Valleys in Nebraska and in the Arkansas Valley in Kansas. The water supply in the region is more than ample for the land now irrigated—$4\frac{1}{2}$ million acres. These developments range in size from a few acres to tens of thousands of acres. Proposed developments will absorb the surplus water and make it possible to irrigate an additional 5 million acres.

Extensive work is required to rehabilitate most of the private systems to insure a reliable water supply in quantities suited to the pattern of the agriculture. Both main canals and individual farm distribution systems need rebuilding to permit use of the most efficient methods of irrigation.

With the change from a dry-land to an irrigation economy comes an entirely new set of problems that must be met if irrigation is to exist permanently. It calls, also, for an effective educational program relating to irrigation and proper water use. Wastage of water, in addition to creating or aggravating the drainage problem through water-logging and salinity, washes away valuable plant nutrients, increases erosion both in ditches and on fields, requires a higher ratio between storage and use, increases operating costs, and reduces production.

All new irrigation developments should be based on sound agricultural analysis to ensure that the water is used only on land that will support an efficient permanent irrigation economy. When the land has been selected and the water supply developed, farm plans should be developed by technicians to include establishment of a complete farm irrigation system with the structures necessary to control, measure, and distribute the water; a layout for the subjugation of the land; a surface and subsurface drainage system; designation of fields and the adapted method of irrigation; and crop rotations based on the agricultural economy of the area. The plan will provide for protection of irrigated land from flooding and silting from adjacent land. It will also outline a water-use program giving consideration to available water supply, climate, slope, soils, and crops grown.

Soil fertility can be built up and maintained by legumes and grasses in crop rotations, barnyard manure, crop residues returned to the land, green manure crops, commercial fertilizer, and cover crops. Pastures and meadows in long-time rotations on irrigated land often produce as high an income as the cash crop to be grown later.

Wind erosion control measures include special tillage practices, cover crops, residue management, windbreaks, and strip cropping.

The irrigation practice known as "water spreading" has rather wide adaptation in the level areas of the rolling plains and rough broken areas of the Northern Plains range land. Flash runoff from small drainage areas is utilized to supplement rainfall. The structures required to distribute the flow are simple and usually automatic in operation to permit use of runoff whenever it occurs. Where water spreading is adapted it insures stability of the feed base and thus is an important conservation measure in areas of limited rainfall.

### Water use and control

The ways in which rainfall is conserved and runoff and stream flow are controlled and used often make the difference between successful and unsuccessful crop or livestock production. Variability in rainfall which follows no fixed pattern imposes the need for dealing with recurring periods of drouth, adequate rainfall, and floods. The type of rainfall requires that throughout the region measures both to conserve water for use by plants and to control excess water for its distribution and safe disposal be employed. Emphasis on the conservation or

control of water varies from east to west.  Prevention of water damage to agricultural land and improvements is the main job in the eastern part of the region where rainfall is heaviest.  Elsewhere, the main problem is to conserve as much rainfall as possible.  The mountain areas have special significance in water conservation, since stream flow originating there is used for irrigation, power, mining, and domestic purposes.  The significance of water use in the west has been recognized by Congress in Public Law 534, passed in 1942, which gave first priority for use of water originating west of the 100th meridian to people who live there.

Aside from its erosion aspects, the wastage of water has most serious consequences west of the 100th meridian.  There, small amounts of added soil-moisture storage materially affect yields.  Recent studies in the High Plains show that 13 per cent or 2.34 inches of the average 18-inch annual rainfall is normal runoff.  Terraces have been found to make 0.8 inch more water available for plant use.  The rest of the runoff is lost through evaporation.  This small amount of moisture increases wheat yields 2 to 4 bushels an acre.  This is a gain of 20 per cent or more over normal yields.

Because the moisture supply is limited in so much of the region, particular attention must be given to the multiple use of water.  Storage in farm ponds and range reservoirs is an example.  Ponds and reservoirs furnish water for livestock and opportunities for recreation.  Properly fertilized and stocked with fish, they furnish sport and food.  Many of them supply water for irrigation of farm gardens and for domestic uses.

*Flood control.*  Need for runoff and waterflow retardation and soil erosion prevention in the interests of flood control is region-wide.  The need is greatest in central North Dakota and in eastern South Dakota, Nebraska, and Kansas, where uncontrolled water and silt cause serious damage.  In Montana, Wyoming, and western South Dakota and Nebraska, the main damage occurs in the intensively irrigated areas, which lie on the alluvial bottoms and terraces of major streams.  Tributary streams entering the major rivers cross the bottoms and terraces either entrenched in canyonlike channels or spread over alluvial fans.  During periods of high runoff, the channels are cut deeper and widened, canals and ditches are silted full or washed out, and irrigated land and crops are washed out.  To alleviate flood damage caused by water and silt, remedial measures at public expense are needed where local resources are inadequate and commensurate benefits can be produced  Public expenditures must be supplemented with private expenditures if the remedial program is to be fully effective.  For example, to bring about a maximum reduction in damage, major gully-control structures must be backed up with a complete conservation program on the watershed.

*Drainage.*  Drainage problems occur in all parts of the region.  Evidence indicates that 60 per cent of the $4\frac{1}{4}$ million acres now irrigated and the 5 million additional acres proposed for irrigation will require some drainage.

Three factors create the need for drainage on irrigated land: excessive application of irrigation water, loss of water from main canals and laterals by leakage, and substrata that offer resistance to vertical percolation.

Adequate investigations of soil and geological conditions in an area proposed for irrigation will permit designation of areas where drainage problems will be of a minor nature, and design of drainage systems at the time the irrigation system is developed.

Overapplication of irrigation water can be cured by education, on-site technical assistance, and improved water-delivery plans. Much must be done to rehabilitate existing distribution works and to design new works to reduce the water loss from main distribution systems. Canal linings will reduce transmission losses and can usually be justified economically, but high unit cost and lack of specialized equipment tend to limit their use.

The need for drainage to remove surface water is confined primarily to a narrow belt along the eastern edge of the region during periods of normal or above-normal rainfall. Lack of adequate outlets and channels makes it impossible for individuals to cope with the problem. Over-all planning and technical assistance are necessary to accomplish this job. This is being carried out in many soil conservation districts.

The drainage problem is most acute in the Red River Valley of North Dakota, where a combination of flat topography, heavy soils, runoff from adjacent areas, and a short growing season creates problems which must be solved to permit seasonal farming operations.

### Specialized phases of the conservation program

The Soil Conservation Service activities in the Northern Great Plains, in addition to the tillage, agronomic, and engineering phases, embrace a number of specialized phases of a complete soil conservation program. Among them are farm woodland, wildlife, and nursery activities.

Since 1935, 215 million trees have been planted on 46,000 farms. The majority of these have gone into erosion-control plantings in the form of field shelterbelts; the remainder, in gullies, woodlots, eroded areas, flood plains, and windbreaks around farmsteads.

During the period of intensive planting, many new techniques and procedures have developed which should result in better planted farm woodlands in the future. Tree-planting machines are speeding up the job of establishment. Contour planting and diversion of flood water into the planting site are ensuring high survivals and long-lived plantings. This is especially important on the heavier soils and areas of low rainfall.

There are $6\frac{1}{2}$ million acres of existing farm woodlands in the Northern Great Plains, of which 692,000 acres have been planted. The remainder consists of native stands of hardwoods concentrated along stream courses and conifers scattered along mountain valleys.

The value of farm woodland as an agricultural crop, one that will pay good returns when it is properly tended and harvested, is gradually being accepted by many landowners. Production of black walnut alone on Missouri Valley farms is exceedingly important as a lumber crop. Wood as a fuel represents the most important present use of the farm woodland. But if developed as a source of

fence posts and poles, which can be treated on the farm against decay, and of lumber for home use, farm woodlands would contribute many times more than they do at present. Careful, selective harvesting will perpetuate this crop indefinitely.

Wildlife is also an important farm resource of this region that is being increased as part of the complete soil conservation program. To date 22,168 farm ponds are being managed for fish production. Approximately 2 million fruit-producing shrubs are being planted annually for gully stabilization and for utilization of waste areas in fence corners and other odd and irregular areas found on virtually every farm. These areas soon become homes for many kinds of wildlife.

There are thousands of acres of marshland that can be managed to produce wildlife. Establishment of good management practices will double the return on many marshes. Webster County, South Dakota, alone takes in over one-half million dollars annually from sale of muskrat pelts.

Soil Conservation Service nurseries furnish improved or scarce planting materials. Methods of harvesting, seed cleaning, seedbed preparation, and seeding of new and untried species of grasses are also developed at nurseries. Instructions on their use and on methods of handling accompany each lot of untried species sent to the districts.

These nurseries are responsible for the widespread use of intermediate wheatgrass. Starting with a hatful of seed 10 years ago, the nurseries and soil conservation districts have increased the amount until this now has reached 100,000 pounds annually. Tall wheatgrass, a wet alkali species, is now replacing intermediate wheatgrass in the nurseries.

Of the improved grasses selected by nursery technicians, two species are now certified in North Dakota (Mandan wildrye and Green stipagrass), three species in Nebraska (unnamed varieties of sand lovegrass, switchgrass, and sideoats grama), and two in Kansas (Blackwell switchgrass and ElReno sideoats grama).

Because of the scarcity of suitable and adapted woody species in commercial channels, nurseries supply 4 to 6 million trees and shrubs annually for use in soil conservation districts only. Supplementary trees are purchased by farmers through regular trade channels.

A good deal of progress has been made in education and planning in this region, but the rate of conservation accomplishments is not yet equal to the rate of land damage. Satisfactory progress depends on understanding and active acceptance by the people of the principles of sound land use and soil and water conservation. Organized bodies, such as soil conservation districts, are taking and must continue to take the lead.

# SOIL CONSERVATION AND GOOD LAND USE IN THE SOUTHWESTERN REGION

## CYRIL LUKER[1]

Miles from highway or village, a unique concrete obelisk near the San Juan River marks the only four-state corner in the nation. Here Arizona, Utah, Colorado, and New Mexico have their common corner. And here is the center of 421,404 square miles of sparsely settled agricultural area with physiography, climate, soil types, land-use patterns, and human occupants so varied as almost to defy any but encyclopedic description.

### DESCRIPTION OF THE REGION

This is the area which the Soil Conservation Service calls its Southwestern Region and within which it has been evolving for some 12 years a program of soil and water conservation. This program is today being carried out by farmers and ranchers within more than 200 soil conservation districts, already embracing better than 106 million acres of privately owned land in these four states.

Besides a common corner, these four states have in common a great and consuming dependence upon grass and irrigation water which makes the word "watershed" here more meaningful, perhaps, than anywhere else in the nation. Even the dry-land farming areas are involved in the watershed relationship, because, although not using irrigation water, they often contribute sediment which affects other parts of the watershed.

Within the Southwestern Region are the Colorado Basin, including the Gila; the headwaters of Rio Grande and its chief tributary, the Pecos; the Rocky Mountains; Colorado Plateau; Great Basin; and many minor mountains and mesas. The region has great topographic variety, with rugged mountains, broad plateaus, deep canyons, cliffs, extensive alluvial valleys, bare salt flats, and ancient lake sites. Elevations range from more than 14,000 feet above sea level in the Rockies to less than 200 feet in the desert lowlands of southern Arizona.

In general, precipitation increases with elevation, ranging from $3\frac{1}{2}$ inches in the lower Colorado drainage to more than 40 inches in the mountains. Seasonal distribution varies greatly. In most of the region, precipitation is inadequate to produce satisfactory crops consistently without irrigation. Extreme diurnal temperature variations and excessive heat and cold are typical, with a mean annual temperature of 50° F. in the major part of the region.

Soil types are as varied as the topography, parent rocks, and climate that produced them.

Soils of the Great Plains are derived largely from Rocky Mountain erosional debris and loess blown from these materials. They are, in general, deep to moderately deep, medium to moderately heavy textured with interspersed areas of sandy soils. The Rocky Mountains, Wasatch, and the high mountainous

[1] Regional Conservator, Soil Conservation Service.

areas of Arizona and New Mexico have extremely variable soils ranging from very shallow lithosols to deep, highly organic mountain valley soils. Soils of the Colorado Plateau and Bonneville Basin vary in depth from shallow to moderately deep. They are moderately heavy textured and highly calcareous, and many contain saline deposits. The southern extension of the Basin and Range Province is dominated by soils that are generally moderately deep to deep and moderately heavy, except in southeastern New Mexico where they are sandy.

The recent alluvial soils in the principal river valleys are extremely variable in texture and depth and in many sections are affected by salts and high water table. Where irrigation is by direct diversion of stream flow, deposition of undesirable sediments and colloidal material often causes the soils to become heavy textured and reduces moisture penetration.

*Agriculture and population*

Although irrigated land comprises only 2.4 per cent of the total area, 61 per cent of all farms and 44 per cent of all cropland in this region were irrigated in 1940. The value of irrigated crops is probably 60 to 75 per cent of all crops produced.

The irrigated desert lands are intensively farmed, and land values are high. Citrus, cotton, alfalfa, and year-round vegetable crops predominate. In the irrigated valleys at higher elevations, potatoes, sugar beets, small grains, alfalfa, tame hay, fruits, and vegetables are the main crops. Intensive part-time farming whereby fruits and vegetables are produced is carried on in hundreds of small valleys and in areas adjacent to the larger cities.

The major dry-land farming areas are in eastern New Mexico, eastern Colorado, and northern Utah, although many smaller areas are spotted through the region wherever rainfall approaches adequacy. The dry-land crop area takes in about 3.1 per cent of the total land area, with wheat, sorghums, and beans the major crops.

The greater part of the region, some 72.5 per cent, is used entirely for grazing. Another 22 per cent is covered with trees and used primarily for the production of wood products. A large portion of this forest land, however, contains fair stands of grass and is also used for grazing.

Slightly less than one fourth of the total population of 2,704,424 was classified as rural farm population in 1940. Most of the population is in the major irrigated areas where intensive farming is practiced, while dry-land, range, and forest areas are sparsely settled. In Maricopa County, Arizona, largely irrigated land, one third of the state's total population and also one third of the rural farm population are concentrated. About 79 per cent of the total population and 62 per cent of the rural farm population of Colorado live in three irrigated areas—the South Platte, Arkansas and Colorado, and Gunnison River valleys—which comprise about one third the state's total area. The same pattern prevails in Utah, where about 59 per cent of the state's total population and 30 per cent of the rural farm population reside in Salt Lake, Weber, and Utah Counties, an area with large irrigated acreage and comprising 4 per cent of the state. In New

Mexico, also, most of the people live within irrigated areas such as the Rio Grande, Pecos, San Juan, and Upper South Canadian valleys.

### Historical influences

Indians were the region's first farmers. Spanish explorers found them mostly in the main river valleys using primitive irrigation methods. The Spanish, bringing with them a background of irrigation, settled and began to farm, improving on the crude Indian methods. These two groups were the region's only agriculturalists when the Mormons entered Utah in 1847. The Mormons, in turn, developed irrigation farming. Modern irrigation began in Arizona, Colorado, and New Mexico in the late 1850's and has made rapid progress, particularly after many of the large projects were opened with aid under the Reclamation Act of 1903.

The earliest Spanish settlers brought livestock into the region, but it remained for the last 20 years of the 19th century to witness the great expansion in cattle and sheep raising. This declined in the first years of the 20th century. Development of much of the prairies east of the Rockies was slow until the wheat boom of World War I. Many land problems of today can be traced back to the early land policies of the United States Government which ignored limitation of rainfall and limited water supplies and set a homestead pattern of farm units too small for economic use under semiarid conditions.

As a result, land-use practices today are too often incompatible with sound, long-time husbandry of the soil.

### Watershed relationships

Most of the man-made factors affecting water supply have their origin in the use of range and forest lands on each watershed. Accelerated erosion is taking place on more than 90 per cent of the range and forested lands of the region. Over half of these lands are eroding at a moderate to high rate.

At low elevations where annual precipitation is less than 5 inches, the land surface usually has been fairly stabilized by a gravel or rock cover, although some sandier soils are susceptible to wind erosion. As elevation increases, erosion conditions on lands up to about 6,000 feet are acute because of the wide variation in moisture from year to year and corresponding fluctuation in the quantity of protective vegetation produced. As aggregated surface soils are lost, the less permeable, dispersed subsoils are exposed. Consequently, revegetation of the watershed lands becomes progressively more difficult and increased runoff concentrates to form gullies in the most productive parts—deep soils of valleys.

Depletion of vegetation by improper grazing has materially contributed to the frequency of floods and a rapidly rising toll of sediment damage in the irrigated areas. These two effects of watershed abuse threaten the existence of a large irrigated acreage in the next generation or two, to say nothing of the economic effect on the ranching industry itself.

Damaging floods have occurred with increasing frequency in all the drainage basins of the region. For example, before 1920, such floods swept down the Rio

Grande on an average of every 4½ years. Since 1920, they have come every 3½ years. The increasing sediment load in streams has clogged stream channels and caused damage to irrigation and drainage canals and structures, as well as to land and crops. Most dramatic, perhaps, is the sedimentation of a few large storage reservoirs of the region. To illustrate, McMillan Reservoir in southeastern New Mexico, built in the '90's to store flood waters for irrigation, is nearly full of sediment. Alamogordo Reservoir, built in 1937, to take the place of McMillan, is already seriously impaired and will be virtually useless in 20 years.

The value of conservation measures on watershed lands is too often ignored by farmers who fear that any work on their watersheds will reduce the amount of water reaching their reservoirs. They frequently fail to recognize that the principal sources of water and sediment are not the same. Most of the sediment is produced below elevations of 6,000 feet where precipitation varies from 5 to 12 inches. Most high mountain areas, where the bulk of the water originates, produce negligible amounts of sediment.

At the same time, ranchers are reluctant to reduce the number of cattle or sheep they can graze on watershed lands even though improved range conditions will be of first advantage to them. Since most western watershed lands are publicly owned, it is hard to understand why the public generally does not awaken to the need for protecting them and demand action to remedy the cause of sediment and floods.

Some of the larger irrigation districts in the lower valleys were developed last and have water rights which are junior to those of many small, scattered irrigated areas in the upper valleys. Competition for water by growing municipalities, wildlife and recreation interests, and new industries adds further complications to the water picture in most basins.

### IMPORTANT PROBLEMS AND THEIR SOLUTION

These preliminary observations should point to the fact that water supply, erosion, and land-use problems of irrigated land, range and forest watershed lands, and dry-farm land, are closely interrelated. For convenience, however, work of the Soil Conservation Service in the Southwestern Region can best be described separately for each major land-use division.

### *Irrigation*

Irrigation is essential to farming under the arid and semiarid conditions which prevail in a large part of the region, with water, rather than land, the limiting factor in development of irrigation agriculture. Since virtually all surface flow has already been allotted, there is little opportunity to put more land under irrigation from that source. Some land, principally in Arizona and New Mexico, is watered by pumps, but most ground water areas are already overdeveloped. It is sometimes possible but usually very difficult to transfer water to new lands. So, the proper use of water on lands suitable for irrigation becomes a vital necessity. Authoritative estimates show that less than half the water is actually used to supply crop requirements; the rest is lost through waste evaporation, deep

percolation, and transpiration by unwanted vegetation. Some of the water lost through deep percolation is recovered in return flow; nevertheless, the chief hope for improvement or even maintenance of the present status of irrigation agriculture in this region lies in saving water now lost.

State laws are not always conducive to efficient use of water. "Beneficial use" is necessary to obtain a right to use the water, but beneficial use is not always clearly defined and inefficient use is frequently condoned. Early downstream rights may require the passage of large flows of water, most of which may be lost in transit. The states of Arizona and Colorado need laws to provide for better use of underground water supplies.

Watershed problems affecting water supply have already been described but it should be pointed out that the seasonal and "flashy" nature of runoff has created a serious problem for systems which depend upon surface flow alone for their supply. Many of the small systems depend on such "flash" flows. Thus, many storage reservoirs are needed to distribute water throughout the irrigation season. In addition, the job of water conservation involves work on canal systems and on irrigation structures as well as the final distribution and application of water on croplands.

Many of these small irrigation systems are in poor general condition and need complete rehabilitation of both canals and structures. Some have been in operation from 50 to more than 100 years, with inadequate original technical design and minimum maintenance since then. Now, however, modern methods, materials, and equipment make rehabilitation practical in most cases. Improved headworks, sluicing, and desilting devices are needed, as is education in their proper design and operation. As erosion on the watersheds has increased, damage from side drainages has become an expensive problem, and diversion of side flows by means of structures to pass flows over or under the canal is badly needed on many systems. Few of the water companies have engineering services available. By making such services available, the Soil Conservation Service has given considerable impetus to the improvement of water systems.

Another source of inefficiency has been the multiplicity of canal systems. Consolidation would help save water and increase the efficiency of maintenance and operation, but differing water rights, varying financial conditions of the companies, and human suspicions and jealousies usually make consolidation difficult.

Desire to reduce development costs frequently has led small irrigation companies to use water on less desirable land. Ordinarily, too, poor land is assessed the same as good land, leading farmers to irrigate all land for which they have water, including land that is rough and steep. The Soil Conservation Service encourages careful irrigation and use of land in accordance with its capabilities.

Erosion is a serious problem in many irrigated areas, but frequently it goes unnoticed for a time because tillage obliterates the symptoms. Fields laid out on nonerosive irrigation grades will remove this hazard. Lengths of irrigation runs need correlating with the irrigation method used, the size of the head of water available, soil conditions, and crops to be grown, so that uniform penetration is obtained. This includes precise leveling of the land and construction of

ditch structures to control water closely. Most farms need checks, drops, turn-outs, spiles, and water-measuring devices. Weed control on ditch banks is widely needed. In many places, water is delivered to the farmer in such a small flow that efficient use is impossible. In those cases, small ponds can sometimes store the flow and provide an adequate head for irrigation. With certain modifications, such ponds can also produce fish.

Strong winds are common during the growing season in many of the irrigated areas. It is recognized that trees in the form of farmstead and field windbreaks require a certain amount of soil and water for growth, but it is also known that good windbreaks of the proper composition of trees and shrubs, properly spaced and located, are of definite value in reducing wind velocities. The Soil Conservation Service assists in the planning of field windbreaks when the farmer is convinced that they will reduce wind damages. Windbreaks also furnish shelter and food for wildlife.

After the various physical improvements are made, there still remains a big educational job to enable farmers to *use* their knowledge and improvements to the fullest advantage. They need to know capabilities of their soils, water requirements of various crops, depth of root zones, and soil and moisture relationships. They must learn to judge the available soil moisture and to irrigate without soil erosion or wastage of water. Soil fertility and organic content usually are depleted rapidly in irrigated sections. So, fertilizers, green manure crops, and flexible rotations are needed. The right crops at the right time; weed, plant disease, and insect control; good cultural practices adapted to the needs of crops and the limitations of the soil; maintenance of fertility and organic content —all these practices are essential to good irrigation farming; they save soil and water, and usually bring increased crop yields.

Inefficient distribution systems and wasteful use of water on the land have resulted in drainage and alkali problems that have limited production on or caused abandonment of significant acreages in most irrigation projects. Seepage from storage reservoirs, main irrigation canals, and farm laterals, leaky well casings, and improper use of irrigation water all contribute to water table problems.

High water table or waterlogging is not the only result of poor drainage. Soils in arid and semiarid areas normally contain at least 0.1 per cent or 1½ tons of soluble salts per acre foot. Most irrigation water contains dissolved salts, and if surplus irrigation water cannot drain readily through the soil, these salts eventually will accumulate in the soil to the point where profitable crop production is no longer possible. Control of ground water is an absolute necessity, not only for reclamation of alkali-affected lands, but also to ensure the permanence of existing irrigated lands. Excessive salts must continually be leached downward and out of the root zone through natural or artificial drainage.

Drainage of irrigated lands must be based on knowledge of the source and movement of ground water, permeability and stratigraphy of the soils, and the nature of the alkali. Controlling the source of seepage water is important to effective drainage. Sealing pervious canals and reservoirs with clay, bentonite,

concrete, or asphalt is usually the most logical means of eliminating seepage, but it is costly. In some marshy sites, because of topography or soil type, drainage is not practical. Such areas may be developed and managed to produce muskrats, waterfowl, and other wildlife.

The Soil Conservation Service is assisting farmers to control the acreage of irrigated lands affected by high water table and salts and to reclaim as much of the present affected acreage as possible. Such work is essential to a permanent irrigated agriculture. But perhaps 90 per cent of the job is yet untouched.

### Range and forest lands

Range and forest watershed lands engage a large share of the efforts of the conservationists of the Southwest Region in their assistance to soil conservation districts. These lands are of special concern because nowhere in the country is the use of range and forest lands in the watersheds of more critical importance to the entire economy.

Since sources of data do not distinguish between range and farm livestock, it is impossible to determine accurately the range livestock population. The 1945 agricultural census for the four states indicates that roughly 3½ million beef cattle, a little over 6 million sheep and about ¼ million goats subsisted chiefly on range. In addition, some ¾ million dairy cattle and horses make use of range.

More than half the total range area is in federal ownership. A major part of the federal grazing lands is in the so-called desert zone where public domain predominates and in the high mountains which are largely national forests. Private ownership, together with lease of state lands, occurs chiefly in the vast intermediate zone. These zones overlap greatly but serve to delineate characteristics of climate, soil, vegetation, and type of use which affect the work of range conservation.

The arid "desert" area has an annual precipitation of 9 inches or less, high summer temperatures, and high evaporation. Present vegetation is principally desert shrub with relict areas of desert grass, formerly widespread but severely depleted during recent generations. The balance of nature is precarious for perennial grasses and they are quickly destroyed by misuse. This zone has elevations up to about 5,000 feet, and it comprises about 28 per cent of the region. Little of the water supply but much of the sediment in the streams comes from this belt.

The intermediate zone has a precipitation range from 10 to 20 inches. Vegetation types include the short-grass plains, pinon-juniper, sagebrush, scrub oak, and other "browse," and ponderosa pine areas. All these types, under natural conditions, support a good herbaceous cover of grasses adapted to the arid and semiarid conditions, and consequently this zone is the most important one in production of range livestock. Elevations range from 3,800 to 8,000 feet, and the zone includes about 62 per cent of the region.

The third zone includes the high mountain areas. It has precipitation of 20 to 40 inches and occupies elevations from 7,500 to more than 14,000 feet above sea level. Virtually all the timber lands occur in this zone, but there are also

extensive wet and dry meadows and open grass "parks." An understory of herbaceous vegetation, suitable for grazing, exists except in limited areas where forests are too dense to allow its growth. It contains about 10 per cent of the total area of the region and yields a high percentage of the water supply but little of the sediment of southwestern streams. Virtually all commercial timber production is from high mountain areas in this third zone. The principal tree species are ponderosa pine, lodgepole pine, Engelmann spruce, Douglas fir, and white fir.

Most of the forest land is under federal ownership, principally as national forests. Areas within the national forests, state forests, Indian reservations, and other small areas in federal ownership are under management, and cutting, in most cases, is carefully regulated. Some of the larger timber owners are showing interest in the management of their holdings on a sustained yield basis. Some of the farmers and ranchers owning woodland areas within soil conservation districts are making use of the technical assistance available to them from the Soil Conservation Service in the management of these areas. Farmers and ranchers as a whole, however, have not shown much interest in the proper management of their woodlands. This is largely because they do not realize their full value.

The importance of timber management can hardly be overestimated. Irreparable damage through injudicious timber cutting, followed by overgrazing, has already been done to some areas in terms of timber reproduction, loss of soil, and increasing flood hazard. Timber cutting in the Southwest offers certain erosion hazards under the best of conditions, but if only mature trees are cut, leaving a few seed trees per acre and all of the straight-growing immature trees, a good timber stand can be maintained. Erosion can be prevented by using slash-to-block skid trails and roads that are no longer needed, where this practice will not cause a fire hazard. If cut-over areas are protected from fire and overgrazing, vegetation of all classes will quickly cover the disturbed soil.

Improper timber cutting, coupled with overgrazing, encourages spread of sage and oak brush, pinon, juniper, mesquite, and other species of low value for grazing or for erosion control. Once these species are established, eradication is slow and expensive. Proper management of the land and vegetation is the first step in solution of this important problem in many watershed areas.

Depletion of the grass cover has reduced the available feed for livestock to the point where livestock numbers now carried on southwestern ranges are probably not more than half that of former years. At the time this region was opened to settlement, there were vast, accumulated reserves of vegetation, and no one knew proper grazing rates. Before such rates were known, ranges were stocked on the basis of the reserve productivity. Expansion of the livestock industry was phenomenal, and widespread depletion occurred before it could be controlled.

Roads, railroads, trails, lumbering operations, mining, and, in fact, every use by man contributed its share to range depletion. There is no indication that climate or precipitation has changed materially. Range use has often been based on the vegetation produced in years of more favorable rainfall. This has meant
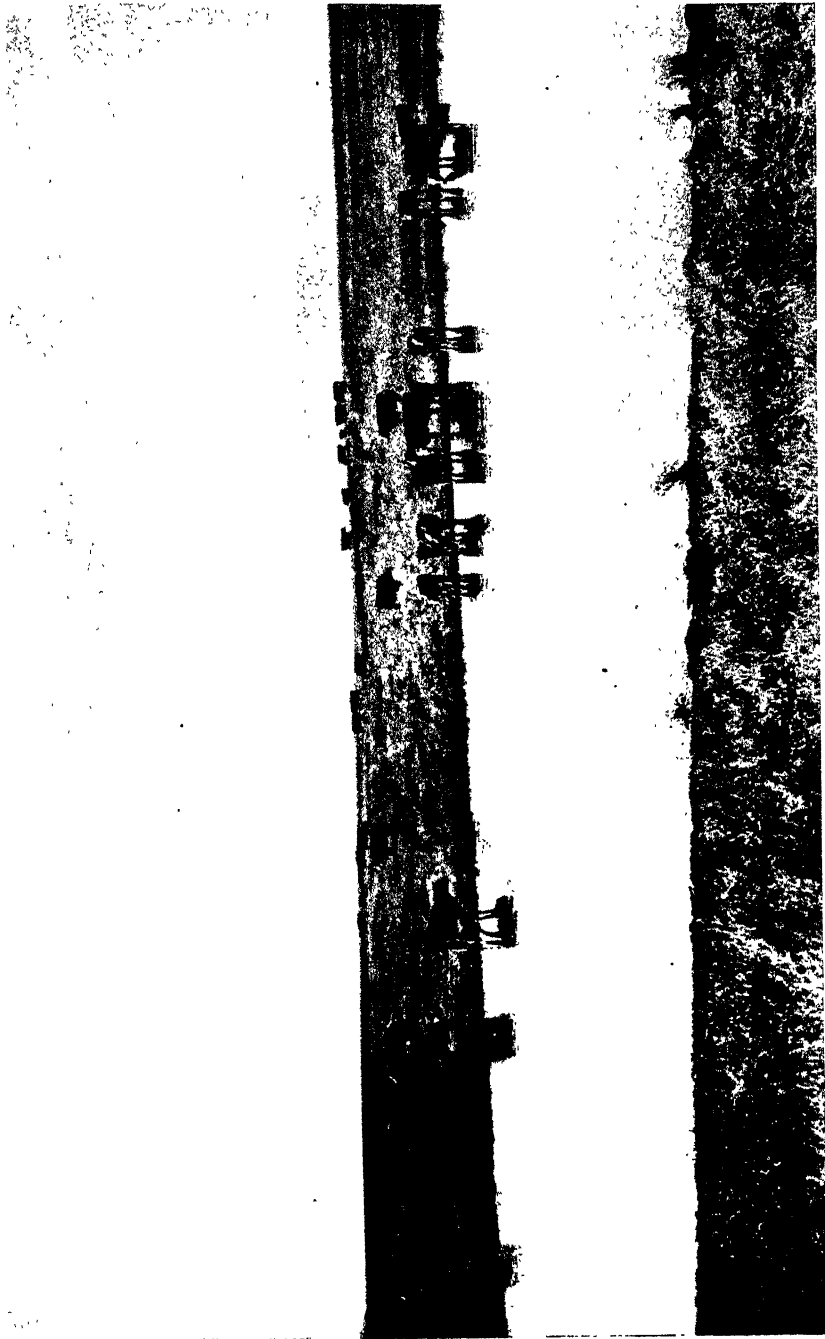
PLATE 8. GRASS IS THE CROP! THE MOST IMPORTANT SOIL CONSERVATION PRACTICE ON RANGE LANDS IS MANAGEMENT. THIS MEANS ADJUSTING AMOUNT AND MANNER OF GRAZING TO THE FORAGE THAT NATURE PRODUCES. STOCK WATER FENCING, GULLY CONTROL, AND OTHER MECHANICAL MEASURES FACILITATE GOOD MANAGEMENT

damage to the range during drouth periods. Likewise this region has its full share of uneconomic operating units that "mine" the range in an effort to stretch resources.

The use pattern and the nature of southwestern ranges make the treatment of erosion different from that in humid regions. The low per-acre income makes it impractical for operators to attempt expensive treatment. The most important treatment and the only one that can be applied to all range land is proper management.

Reduced to its simplest terms, range management means adjusting grazing by livestock to the forage which nature produces. Fortunately, management practices such as rotation and deferred grazing, which require no large outlay of either labor or materials, are generally effective in producing both maximum forage yields and maximum soil conservation. Supplementary treatments like fencing, stock-water development, gully control, water spreading, and diversions may serve for erosion control or to facilitate good use of the range, or for both purposes.

Where lands have been depleted by overgrazing or abandoned after unsuccessful cultivation, reestablishment of grass or more desirable species of grass can sometimes be accomplished by conservative grazing and proper handling of livestock. If few desirable range plants are present, however, artificial revegetation may be the only answer. Species used in range reseeding should be capable of producing a permanent usuable range pasture, and reseeded areas must be protected until well established. Some seeds are difficult to collect from native stands but can be produced from farm plantings.

Reseeding of range and farm lands gives the stockman an opportunity to establish range pastures which will provide grazing at seasons when his other range units are unproductive or should be rested. The replacement of poor and undesirable vegetation with desirable range forage plants controls erosion, is of great economic value to the livestock industry, and also aids irrigation interests by keeping sediment out of stream channels, reservoirs, and canals.

In addition to grazing and lumbering, range, and forest, watershed lands have other uses such as recreation, wildlife production, water supply protection, and mining. Many of the complications in range use and management result from the requirements of its multiple uses.

*Dry-land farming*

Land capability is the most important factor in determining the use that is to be made of land in the dry-farm areas of the region. Unless these lands are farmed with crops and practices adapted to their capabilities, they probably should not be considered as arable lands. The soil erosion hazard is high; its solution is complicated. Most of the land is subject to wind erosion damage unless adequately protected. Even so, soils are not generally the major factor limiting production because they are usually deep and, although low in organic matter, they produce abundantly during wet years.

Precipitation is erratic in most areas with annual extremes of less than 8 inches to more than 40 inches. Seasonal variations are as extreme as the annual varia-

ations. Dry years, when crops that would provide protective residues are hardest to produce, are the years when cover is most needed. And, during wet years when ample residues could be produced, many farmers either remove everything at harvest or graze off the stubble before spring. Then, if blowing starts, they must rely on emergency tillage, a poor substitute for crop residues in controlling wind erosion.

Most of the better dry-farm land in the region falls in capability Class III, on which cultivation is considered safe if intensive measures are applied to cope with the hazards of climate. Land in areas where uncertain precipitation makes continuous cultivation questionable, and where special treatment or practices are required for protection against wind erosion, are placed in Class IV. If soil characteristics are unfavorable, the lands are nonarable and are placed in Classes V, VI, and VII. Such areas should be used only for grazing and every effort made to maintain the maximum cover of vegetation the soils will support.

Virtually all areas containing land of Classes II (cultivated safely with easily applied conservation practices) and III have two or more generations of farming behind them, and farmers there are more easily convinced of the accuracy of land classification than in the newer areas where there is usually considerable Class IV land. A large part of the land on the marginal side of Class IV and in Classes V and VI, although productive in wet years, constitutes a special wind erosion problem in most areas during years of less than normal precipitation when production of an adequate crop residue cover is most needed and hardest to produce.

In the absence of long-time climatological information and cropping history, it is sometimes difficult to know whether land should be in Class IV or in Class V or VI. On such lands, it is still more difficult to obtain farmer acceptance of land capability classifications because of high yields during wet years which are too often considered normal.

The last 5 years have been unusually favorable in some areas for both crop yields and prices. Many thousands of acres of good range land have been plowed up, and more will probably be plowed until farmers again experience low yields and prices. Most of this recently plowed land will be abandoned ultimately and will be a liability until it is reclaimed through costly revegetation. The only protection from land speculators and gambling farmers during favorable crop years will be land-use regulations imposed and enforced by local people.

As might be expected, water conservation practices are more readily accepted than other conservation practices in the dry-farm areas. Contour farming is increasing steadily in most areas. Terracing, both as a water conservation practice on the flatter slopes and as a supporting practice for contour farming on slopes subject to water erosion, is increasing slowly. Obstacles to a rapid increase include difficulty of adjusting large-type machinery to terrace farming, inadequate data to prove its value, and the slowness of establishing grassed waterways. Mechanical stabilization is impractical in most areas and the intervals between effective precipitation are usually so long that establishment of an effective sod cover is slow. Contour farming is recommended for all sloping land

except deep, sandy soil where water intake is rapid or where uneven topography or excessive slope makes establishment of contours impractical. In these cases, farming across the direction of the prevailing winds is recommended.

Strip cropping, though on the increase in some areas, has not been accepted generally. A pattern of winter wheat, fallow, and winter wheat, the fallowed strips alternating with the cropped strips, is proving to be a good practice for both wind and water erosion control in the northern part of the region where a large portion of the precipitation comes in winter and spring. Farmers generally recognize the value of strip cropping but object to the practice because their equipment is better adapted to large field operations. In the southern part of the region, where most of the moisture comes in late spring, summer, and early fall, the Soil Conservation Service and the state experiment stations advocate a flexible cropping system. This includes the use of fallow, preferably in a strip-crop pattern, only when subsoil moisture reserves in the fall total less than 4 inches of stored moisture. When subsoil moisture is more than 4 inches, the use of sorghums in strips is recommended. Strip cropping for the protection of nonresidue-producing crops such as beans is not being used to any great extent. Farmers generally are unwilling to narrow their strips to the extent necessary for protection—eight rows or less.

Residue production and management should always be the number one practice for all dry-farm land because it is equally valuable for water conservation and water and wind erosion control.

The major problem confronting boards of supervisors in getting soil conservation practices adopted in dry-farming soil conservation districts is the farmer who is not yet ready to acknowledge that he is trying to farm land that should be retired to sod cover.

### CONCLUSION

This, then, is the picture of soil and water conservation in the Southwestern Region. Nowhere is there greater dependence upon soil and water, and nowhere more varied and difficult problems in their conservation. But a good start has been made, and the people of the region are joining forces with the Soil Conservation Service and other agencies to tackle the job with ever-increasing understanding and enthusiasm.

# SOIL CONSERVATION AND GOOD LAND USE IN THE PACIFIC REGION

## J. H. CHRIST[1]

### DESCRIPTION OF THE REGION

Diversity is the attribute most characteristic of the Pacific Region, its physiography, climate, soils, and agriculture. The Pacific Region of the Soil Conservation Service is made up of the five western states—California, Idaho, Nevada, Oregon, Washington—and the Territories of Alaska and Hawaii. Only the five states will be considered in this discussion.

This region has the highest and lowest elevations in the United States and the wettest and driest points; and agricultural endeavors range from subtropical horticulture to short-season grazing of subalpine summer ranges.

Most of the cultivation is carried on in intermountain areas. An almost continuous range of mountains, the Cascades in the north and the Sierra Nevadas in the south, parallels the coast line about 120 to 200 miles inland. Between this range and the Coast Range lie the two major valleys—the Central Valley of California and the Williamette-Puget Sound Trough of Oregon and Washington. Each valley is more than 50 miles wide, and their combined length exceeds 1,000 miles.

The only major break in the Coast Range occurs immediately north of the Columbia River mouth and isolates the majestic Olympic Mountains to the north. Throughout the southern half of the Coast Range, long narrow structural valleys parallel the coast; farther north, erosional river valleys lie more nearly at right angles. In Nevada and southeastern California the valleys were developed under arid or semiarid conditions and are of the desert-bolson type.

In the intermountain country east of the Cascade-Sierra Ranges lie several uplands known as the Columbia, Snake, and Great Basin Plateaus. These are commonly the surface of vast lava flows, now thinly covered with soil. Originally they supported timber, grass, and sagebrush in varying mixtures. Three fourths of the area of the region is forest and semiarid range. Most of the mountainous parts of this area are within national forests, and much of the open range is administered by the Interior Department.

Climatic conditions within the region are mainly dependent upon four factors: elevation, distance from the ocean, position with relation to mountain barriers, and latitude. Moisture-laden winds off the Pacific drop the main part of their burden on the west slopes of the mountains and pass over the east slopes relatively empty. In general, then, the higher areas are wetter and cooler than the lower areas, and the inland areas are drier and have a wider temperature range than the coastal areas. "Rain shadows" on the lee sides of mountain masses are drier than the exposures to windward. And the northern states are more moist and cool than the southern. Precipitation, most of which occurs in winter,

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is generally of low intensity in the north and of progressively higher intensities southward. The intermountain area east of the Cascades is subject to summer thundershowers.

Parent materials of soils in the Pacific Region range from the granitic core of the Sierra Nevadas through the South Coast Range sedimentary rock and the lava plateau basalts to the glacial outwash of the northern valleys and the wind-modified recent alluvium of the southern deserts. Extensive areas of highly organic soils also occur; notably the 250,000 acre "Delta" in California's Central Valley which produces some $25,000,000 worth of crops in an average year. Dense forests, grass range, and sparse desert vegetation have exerted their influence. Acid upland soils are found within a few miles of alkaline flats, and highly fertile wind-laid soils may abut leached glacial deposits. All of this means that the measures applied to soil conservation problem areas must be many and must be prescribed on a local basis.

Farmland values in parts of the region are high, even without current inflation. Before the war, for example, citrus and walnut orchards in southern California were commonly valued at from $1,500 to $3,000 per acre; walnut and filbert orchards in Oregon and Washington from $600 to $1,500; and, in Skagit County of northwest Washington, fertile bottom lands growing vegetable seeds and other specialty crops from $750 to $1,200 per acre.

Only one fourth of the region is in farms and ranches, and less than one fourth of the land in farms is cultivated. Nevertheless, more than one fifth of all cash received by all farmers for all crops in the United States in 1944 came to the farmers of this region. Intensive growing of highly specialized crops dominates the agriculture—California's oranges, lemons, and walnuts, Oregon's seeds and bulbs, Washington's apples, Idaho's potatoes, and Nevada's large stock ranches.

Relatively small areas in the Western States are suitable for further clearing. Most of these are on farms now fairly well developed. On most farms there are varying acreages that are better suited to timber than to any other crop. Farm woodlands provide opportunity for more intensive management, and consequently higher cash returns per acre, than the commercial forests. Moreover, farm woodlands have the added advantage that they are near the markets and the timber is relatively easy to get out. With the shortage of good high-grade lumber, species that once would not pay the cost of taking them from the woods are being cut and sold at good prices. Also, by-product plants are being built to use material formerly left in woods. Many of the farm woodlands, however, are inadequately managed for timber production because of the operator's lack of knowledge of methods of handling timber properly or of ways and outlets for marketing the materials produced.

The population of the region is half as dense as in the nation as a whole, with the greatest concentration in a narrow strip along the coast. In 1940 two thirds of the people were classified as urban, living in cities of 2,500 and larger. Almost one third lived in San Diego, Los Angeles, San Francisco, Portland, and Seattle. Elsewhere, the distribution of people follows that of the agricultural land.

Erosion by water occurs on nearly all cultivated land and range land in this

region. It is the most widespread problem on irrigated land. Probably the most serious erosion is on the steeply sloping cultivated fields of southern California and in the Palouse area of the Northwestern States. In general, forested areas show no active erosion, except when under extreme grazing use or conditions of recurrent forest fires.

Erosion by wind is serious in many small areas in this region. These spots occur along the coast line from Canada to Mexico. Nearly all are the direct result of man's misuse or abuse of the land. This form of land damage originates on recreational, cultivated, or overgrazed areas along the coast or on cultivated range areas in the interior. Wind erosion does not occur on wooded areas.

### IMPORTANT PROBLEMS AND THEIR SOLUTION

Six general farming types are recognized for the purpose of this discussion of soil and water conservation problems and their solution.

#### *Irrigated farming*

Totaling nearly 10 million acres, the irrigated land in the five Western States constitutes 46 per cent of all the irrigated land in the nation and 30 per cent of all cropland in the region. This irrigated land is the most intensively farmed land in the region.

Roughly half of the irrigated land is in the Central Valley of California. Other major areas are California's citrus belt and Imperial Valley; the irrigated areas in southern Idaho, central Washington, and central and eastern Oregon; and the mountain valleys of Nevada. Small areas are scattered elsewhere wherever a combination of available water and arable land exists. Even in the humid northwest, sprinkler irrigation is being installed by many farmers for use during the rainless summer months.

Virtually all the nonirrigated cultivated land is capable of greater production with supplemental irrigation, although much of it is too steep for irrigation except by sprinkler. Since most of the precipitation of the region occurs during the winter months, much of the water used for irrigation must be held by some means until summer. Summer snowmelt can be used from direct streamflow, but winter and spring snowmelt and winter rainfall can be held only by reservoir storage.

Better use of the developed irrigation water in the region would make available about 9 million acre-feet. The equivalent of some 2¼ million acres could be irrigated from the water so saved or it could be used to supplement already deficient acres. This could be accomplished by a conservation program including improved water application, reduced delivery losses, delayed early-season irrigation, elimination of water in canals during the nonirrigation season, and groundwater recharge by spreading of flood waters. The cost of such a program would be much less per acre-foot of water than are many of the huge storage projects.

Erosion is the most widespread problem on irrigated land. It occurs to some degree wherever surface irrigation is practiced. On slopes of more than 2 per cent it is a serious problem wherever row crops or orchards without cover crops are irrigated. Moderate to severe erosion is taking place on more than half of the irrigated land, and the problem is critical on almost a fourth.

Crop yield records of some of the older irrigation projects show a general de-
cline. This is particularly true where soil organic matter and plant nutrients
have been depleted through intensive cropping and where excessive application
of water has resulted in loss of topsoil by erosion and of plant nutrients through
leaching.

Besides the loss of plant nutrients, excessive or improper irrigation in many
areas has resulted in waterlogging of soils and the destructive accumulation of
toxic salts (alkali). Slightly more than 2 million acres, one fifth of the irrigated
land, require the control and removal of alkali or seepage water. Thousands of
acres in the older irrigated sections have been made unproductive by waterlogging
due to the general rise of the water table through the addition of seepage water
and from deep-percolation loss of water applied to irrigated crops.

Drainage of irrigated land usually requires extensive investigation of the deeper
subsoil and underlying strata to determine the source and movement of surplus
water and the methods of controlling this water. Improved drainage often re-
quires modification in the methods of irrigation and rate and amount of irriga-
tion applied.

Where alkali is a problem, drainage is usually the first step in restoration,
which usually involves leaching the soil with water either with or without some
chemical treatment. Growing alkali-tolerant crops and plowing them under as
green manure aids in the leaching process. Sometimes alkali is due to poor-
quality water caused by impregnation of salts in transit or by concentration of
salts in ground-water sources of supply. In these instances it is necessary either
to dilute the water or to find new sources.

On about one fourth of the irrigated land, on-the-farm water supplies are in-
adequate, either in seasonal quantity or availability throughout the growing sea-
son. Denuded watersheds, silted reservoirs, failing conveyance systems, and
declining water tables are some of the causes. But lack of efficiency in the use
of water on farms is the biggest factor of all. Improperly laid out farm distribu-
tion systems, poor head control, and the irrigator's general lack of understanding
of soil-moisture relations are the principal reasons.

In establishing a systematic soil and water conservation program, it is neces-
sary to consider these problems on an area-wide as well as on a farm-by-farm
basis. It may be necessary for the farmers to take organized group action.
Some of the treatments commonly worked out by a group include stabilization
of underground water supplies by artificial recharge; rehabilitation of storage
reservoirs, canal consolidations, and improvements; flood protection of irrigation
works; canal lining to eliminate seepage losses; removal of debris and bed-load;
drainage of irrigated land; and development of improved water rotation sched-
ules. This group action is preliminary to and contributes to establishment of
soil and water programs on individual farms.

Whether on new land or established irrigation land, the first step in solving the
conservation problem of the farm is to survey its soil and water resources. The
profile limitations of the soils and their water-holding capacities and ability to
take in water need to be mapped so that irrigation, cropping, and soil manage-

ment can be planned to make the best use of the land and to avoid alkali and drainage problems.

When seasonal or total water supply is found to be short, adjustments may be made in the choice, or in acreage, of crops having different water requirements.

Control of erosion on irrigated farms may require changes in land-use and cropping practices. Converting steep lands to pasture, growing more soil-improving crops and fewer row crops in rotations on the more level land, making better use of manures and crop residues, and fertilizing are improvements needed on many farms. Changes in the system and method of irrigation may also be called for. The irrigation method must be safely adapted to the land conditions and the crops grown. Land leveling must be designed to fit the irrigation method and provide uniform application of irrigation water. Some field ditches and laterals need to be moved to lessen the irrigation gradients and shorten the length of runs that are contributing to erosion and low efficiency in water use. Other specific measures that may be required as part of the farm conservation plan include subsoiling, field drains, alkali control, and waste-water disposal.

Planning alone is not enough, however. To eliminate erosion, waterlogging, alkali, and leaching, the farmer himself must be able to apply the water to the soil in the manner for which the farm irrigation system and facilities are designed. This requires technical assistance to set water heads properly and to show what constitutes a nonerosive stream and reasonable waste water and, finally, when to irrigate and how much to apply in each irrigation.

### Large-scale nonirrigated farming (cool temperate)

Measurements of soil losses indicate that, under the present cropping system, abandonment of cultivation will be under way in 40 years in southeastern Washington and adjacent parts of Idaho and Oregon. Here is the large-scale, nonirrigated farming section of the cool temperate area that is capable of producing a crop annually without irrigation. Wheat is the major crop; peas, barley, alfalfa, sweet clover, and other crops are used in rotations.

From the standpoint of damage to the productive capacity of the nation's farm plant, erosion is of more immediate consequence here than in any other problem area of the region. In the short 60 or 80 years since cultivation of these lands first began, 5 to 10 per cent of the average farm has become submarginal for wheat production.

The land of this area is of three main types, the Palouse, the Nez Perce, and the Blue Mountain foothills. The Palouse, which lies mostly in the State of Washington but extends into Idaho, reminds one of sand dunes. The slopes are short, choppy, and highly irregular. The soils, however, are a heavy silt loam. The Nez Perce prairie of Idaho, which adjoins the Palouse, is much like the Palouse except that it is generally smooth or gently rolling. The Blue Mountain foothills present a similar appearance except for two things: they are tilted so that the upper edge becomes the Blue Mountains, and they are cut by transverse, deeply entrenched canyons. The soil on these ridges is mostly an extremely mellow silt loam that gullies far more easily than the soils in the other two areas.

PLATE 9. IRRIGATION FARMING REQUIRES ECONOMICAL AND EFFICIENT USE OF PURCHASED WATER. CONTOUR IRRIGATION AND CONTROL OF WATER FLOW WITH SIPHONS ARE THE ANSWERS OF THIS ASHTON, IDAHO, FARM TO THE PROBLEM. EXCELLENT MOISTURE PENETRATION, GOOD FIELD COVERAGE, AND NO EROSION ARE HIS RESULTS

The three types have had remarkably similar history and use through the last 60 to 80 years, but they now present three distinct erosion problems. Safe use of all this land requires proper crop rotations, adequate amounts of green manuring, use of all plant residues, and legume-grass as hay or pasture on all steeper slopes most of the time. Because of the topography, the conventional strip cropping and terracing do not fit the Palouse area. Here, approximately a third of the land should be in hay or pasture most of the time. And the hilltops as well as the steeper slopes must be covered with either alfalfa-grass or sweet clover grass most of the time. Safe use of both the Nez Perce and the Blue Mountain foothill farmlands must include the general use of strip cropping and terracing. In addition, in the Blue Mountain foothills special effort is required to prevent the formation of gullies.

Permanent agriculture is possible in all of these areas by the consistent use of land within its capabilities. When that is attained the production of livestock rather than of cash grains will be the mainstem of the farming. Then "livestock products with some grain" will be marketed, instead of the "wheat and peas with a little livestock" marketed today.

### Dry-land farming (semiarid)

All in all, the dry-farmed grain land, where grain and fallow alternate in the cropping system, comprises the largest single type of farm enterprise in the region. In the Columbia Basin of central Oregon and Washington and in the upper Snake River country of southeastern Idaho, spring and winter wheat are the principal crops. Along the foothills of the Sacramento, San Joaquin, and interior sources of coastal streams of California, barley takes the lead. Here dry-land farming is practiced on a large scale with units ranging from a few hundred to a few thousand acres in size. Grain production is the sole enterprise on many farms; on others, it is combined with the production of livestock. Elsewhere are scattered areas of dry-farmed land around the fringes of irrigated mountain valleys and as parts of irrigated farms and ranches.

Erosion on the dry-farmed land ranges from slight to severe. In general, rates of water erosion have been less rapid than on most other cropped areas of the region, primarily because of lower rainfall. Wind erosion occurs in localized areas. It may become severe during successive drought years, but for the dry-farmed land as a whole, it is a lesser problem than water erosion.

The expansion of grain production during and since the war has resulted in many thousands of acres of marginal land being farmed to grain. Some of this land was cropped during the first world war and was later abandoned or converted to grassland; some was new land that had never been plowed. These and other marginal areas will be the first to be abandoned when grain supplies again become a price-depressing factor. Rather than being abandoned to weedy vegetation of low grazing capacity, these areas should be seeded to adapted perennial range grasses. Restored to grassland, they would be some of the better range of the region.

Seeding marginal land back to grass is one problem, but the larger

of establishing conservation programs on the dry-land areas that are suitable for continued cropping and on the range land that is a part of operating units. For the most part, operating units are of adequate size for economical production.

Conservation practices and treatments required on the dry-farmed land are essentially the same as those on the more humid nonirrigated land. The differences lie mostly in method and intensity of application. Because limited rainfall is a characteristic common to all dry-farmed areas, moisture conservation assumes special importance. Such practices as rotary subsoiling and chiseling grain-stubble land in fall are proving effective in getting moisture from melting snow and from winter rains absorbed by the soil. The rotary subsoiler, unknown 10 years ago, was used on several hundred thousand acres last year in Idaho and Washington and offers promise of much wider use.

Crop rotations have not assumed the importance they deserve in most dry-farmed areas. Although significant declines in soil organic matter and nitrogen have occurred in most areas, low rainfall continues to be the major factor limiting crop yields. In the higher rainfall areas (12 to 16 inches) of the Pacific Northwest, the use of alfalfa–grass and sweet-clover–grass mixtures in rotation with grain and fallow is proving practicable. The crop may be used for hay, pasture, and green manure. Sweet clover seeded in alternate rows with spring grain is gaining in popularity on many dry-land farms, especially those not having livestock. Used as a green manure, the sweet clover helps to maintain organic matter and nitrogen. In areas normally receiving less than 12 inches of precipitation, available legumes are not dependable, and here crested wheatgrass and other drought-tolerant grasses offer greatest promise.

There is a lack of knowledge of grasses and legumes and their culture for dry-land rotations in California. Alfalfa and perennial grasses have been grown successfully only on the deep, heavy-textured soils and claypan soils having most favorable moisture relationships. Among other soil-improving crops, vetch, burclover, and the native and introduced lupines show considerable promise. Eventually soil-improving rotations must play a bigger part in the conservation program on the dry lands.

Stubble-mulch tillage is the most widely used conservation practice. No other single practice provides more effective control of erosion during the critical winter and spring following summer fallow. Many improved implements have been developed, and ordinary farm implements have been adapted for use in stubble-mulch tillage. These include subsurface sweeps and chisels for plowing, heavy-duty rod weeders with shovel attachments for weeding and for subsurface plowing on light-textured soils, rotary hoes for packing the seedbed and for distributing clumps of straw that interfere with seeding, and the deep-furrow and press-wheel drills for seeding. With heavy stubble, fall disking before summer fallowing reduces the length of straw and promotes some decomposition. A second cutter bar on the combine and a rotary chain stubble buster are other developments for reducing the length of straw so that it can be handled more easily as a stubble mulch.

Many problems of adapting stubble-mulch tillage to certain dry-farmed areas

are yet to be worked out. Better tillage and seeding implements to handle heavy stubble mulches are needed. The heavy, abrasive soils of California cause extreme wear on all types of sweep implements. The rotary subsoiler for loosening the soil before working with subsurface implements offers promise of overcoming this problem. On soils extremely low in nitrogen, surface residues have sometimes resulted in a lowering of yields. Light applications of nitrogen fertilizers have overcome the depressing effects, and, where they can be used, legumes in the rotations accomplish the same result.

Contour tillage and seeding, contour strip cropping, terraces and field diversions, and drainageways seeded down to grass are supporting practices used according to the needs of the land. Alternate strips of grain and fallow, buffer strips of grass alternating with strips of grain or fallow, and strips of grasses and legumes grown in crop rotations, alternating with strips of grain or fallow, are types of strip cropping used on dry-land farms. Where needed, terraces and field diversions are used to break long slopes or to intercept runoff from higher range land. Stock-water developments are important on many farms to provide the best grazing of land converted to grass and the grazing of rotation seedings. Closer integration of cropland and range land use fits in well with conservation objectives for both of these land uses. Hay and pasture crops grown in crop rotations provide feed to supplement the range and organic matter and cover to improve the soil and control erosion.

### Range land

About 212 million acres, or nearly two thirds of the region, are grazed by domestic livestock. More than 117 million acres of the land grazed are administered by agencies of the federal government. The remaining 95 million acres are owned privately or by states, counties, and municipalities. According to the 1945 agricultural census, about 60 million acres of this land are in farms.

Large areas (about 25 per cent) are totally depleted of their original important forage plants. Still larger areas (nearly 75 per cent) could be brought back to an approximation of their original stands of grasses and browse plants by a long period of protection from grazing. Occasional areas, usually the most remote from a water supply, still reflect their original stand and production capacity.

Classes have been developed for expressing the condition of the range in relation to its potential productivity. These classes are excellent, good, fair, poor, and, very poor. The classes are based on the percentage composition of desirable, less desirable, and undesirable plants in terms of ecological succession and, to some degree, the desire of livestock to utilize them. Other factors used to determine the range condition classes are forage density and vigor, degree of erosion, and amount of litter on the ground. Range condition classes have proved to be a very practical tool in planning conservation practices on range land. They are used as guides for stocking the range and for setting utilization standards.

Because of changes in land use and policies of the administration of public lands, many farmers and ranchers have had to increase the yields of their privately owned range land and to produce more feed on their cultivated land

through more intensive management.   Improved species of grasses and legumes are being used for pastures and hay.   The use of commercial fertilizers has resulted in increased production and better quality feed.   The demand for more livestock feed is also being met in many of the dry-land areas through pasturing soil-improving crops such as sweet clover.

In addition to establishing conservation practices on the cultivated land to provide the maximum amount of hay and pasture for seasonal and reserve feeds, numerous steps can be taken to develop the private land so that it can be used as fully as possible year after year.   Some of these are: Set up seasons of use for the respective natural units; provide fencing so that livestock can be held where wanted; develop water supplies so that they are ample for the livestock and so that they will help in keeping the animals spread out; establish salt grounds so that unused areas will be utilized and the stock kept moving; establish shade and shelter for inclement periods; appraise the forage and set up grazing schedules that will ultimately provide for the re-establishment or strengthening of the most valuable range species; reseed the better areas where, by reason of favorable soils and adequate moisture, success can be fairly well assured; and, finally, maintain the number of animals that, year by year, can be kept on the ranch without overloading its facilities.

Stock properly limited to the supply of good forage turns out more pounds of beef or lamb of a better quality than does stock on a similar area being raw-hided of all the forage it will produce.

### Highly diversified nonirrigated farming (warm temperate)

On the nonirrigated cropland—the spots and stringers, terraces, and hills— in the 50-mile belt along the coast of central and southern California we find the greatest problem in using land without destroying it.   Favored by an oceanic influence, summer fog, and long growing season, both valleys and hills in this belt are used intensively for a wide diversity of crops.   Wherever a water supply is available, irrigation is practiced.   The heavily valued orange, lemon, and wal-nut groves largely take up the irrigated valley floors.   Wash from adjacent slopes piles infertile debris on these groves and further complicates drainage systems already impaired with bed-load sediment.

Some three fourths of the annual precipitation occurs in winter.   Every effort is made to store enough water to carry the crop through the summer to harvest. This is particularly true with spring-planted beans and fall-planted grain, the two principal dry-farmed crops along the southern coast.

Shallow claypan soils are common in this belt.   They are highly erodible even on gentle slopes, as evidenced by small and large gullies; deep, straight-walled "barrancas"; and conspicuous sheet erosion.   Some of the steep and shallow land should be retired from annually planted crops and turned to forage production.

Some of the less steep and the deeper land can be used in long rotations for occasional production of beans and grain.   A suggested rotation involves about 5 years of a grass-legume ground cover, followed by 1 year of beans and 1 year of small grain.   Other land can be continued in dry-farmed beans or grain, pro-

vided certain special practices to prevent erosion and other damage are followed assiduously. The most important of these is stubble-mulch tillage. Operation of equipment on the contour and strip cropping where land conformation permits will offset most of the erosion hazard.

On some of the gently sloping areas of heavy soils near the shore line, tomatoes and other·intensively grown, early-season crops are being produced. Here the practices needed are diversion ditches, terraces, deep subsoiling, and planting in contour strips, in addition to the usual good farming measures.

Grapes for the production of fine table wines are an important crop in this belt. Near Los Angeles most of the vineyards are on the loose sandy soils of the coastal plain. Here wind erosion has already done much damage and re- mains a continuing hazard. Control measures needed include windbreaks and cover crops, which, along with prunings and other plant residues, should be disked over the soil to protect it from blowing and to prevent undue drain on soil moisture.

Around San Francisco Bay, most of the vineyards are on the gently to steeply sloping shallow soils bordering the valley floors. Nearly all these vineyards are being slashed and thinned by gully and sheet erosion. New plantings should be placed on the contour, preferably on contour terraces, and cultural operation should follow the contour. On the established vineyards that are square-planted, a cover crop, especially if well established and growing during periods of heavy rain, offers the greatest possibility for reduction in soil loss. Light disking in early spring to check or kill the cover crop is necessary to prevent loss of the low soil moisture.

### Highly diversified nonirrigated farming (cool temperate)

West of the Cascades and of the Sierra range in California is an area of fertile soil, under abundant winter rainfall and mild climate, that eroded slowly during the first 80 years under the plow. Now the rich soils of the area are being washed away rapidly. Soil nutrients have been depleted to the danger point, mainly through leaching caused by heavy rainfall, heavy cropping, and erosion. The banks of nearly every creek and river are being eroded away at a rapid rate, and rampaging rivers have destroyed some entire farms. Stream-bank erosion in flood stage on these rivers results in costly silting and in eroding of unprotected lands along the way. Sloping and hilly land that was once densely forested contributes to the silt load of the streams.

The foothills and mountain slopes that were once forested in this area are now cut over, and fire has repeatedly devastated millions of acres so that they will not restock naturally. These areas are shallow and of low fertility for agricultural crops other than wood products. They erode easily and rapidly wash down to bedrock. On many of the watersheds long or intense rains send the rivers out of their banks. Most of the farmers depend on outside work for their main cash income.

On farms in this area grow most of the 1,300,000 acres of farm woodlands. Readjustment of the land use and enlargement of farms too small to be profitable

are essential to provide adequate erosion control and water conservation. When managed according to conservation practices these farm woodlands are providing an average annual income of $5 to $10 an acre.

The million and a quarter acres within this area that require drainage extend from the diked tidelands up through the river valley bottom lands to the upland plateaus. Interception ditches at the bases are used to handle seep water and runoff from slopes adjacent to bottom lands. Community drainage ditches are used to move the water from individual farm or group drainage systems on the flat lands to disposal outlets. On extremely low lands that lie below the level of the rivers, pumping is necessary to dispose of the water. In other areas the water is carried away by gravity to the river through tidegates in dikes or through open ditches.

The drainage of these areas assists in the conservation of other land. The intensively managed pastures and cultivated crops on the drained land relieve the pressure on the shallower, less fertile, and more highly erodible sloping land. Where water is available, supplemental irrigation during the dry summer months benefits the establishment and management of these fields.

In orchards and row crops on the hill lands, contour or occasionally cross-slope planting and tillage, crop residues, and winter cover and green manure crops help to hold the land in place and save the winter moisture for use in the dry summer. Erosion on cereal and forage crops on this steeply sloping land is best controlled when the crop is tilled and seeded on the contour and rotated in strips with perennial crops.

Vegetative cover must be replaced on these burned and cut-over slopes if the $3,000,000 or more annual damage from flash floods and stream bank erosion is to be stopped. Reforesting by artificial means is the only way to replace the cover in some areas.

Vegetative cover is also the answer to the sand-dune problem. Sand dunes, confined largely to the coast line and along the Columbia River, cover localized areas totaling nearly 100,000 acres. The shifting sand was encroaching on rich agricultural land, forests, and highways and threatening to impede the ocean-going commerce of the Columbia River. The dunes are now being controlled by first establishing a sand-stilling cover of beachgrass or dunegrass and then tying them down with a permanent cover that includes fescues, vetch, and beach-pea. In maintaining this cover, "bare spots" are treated individually.

# EXPERIMENTS ON THE IMMOBILIZATION OF PHOSPHORUS MINERAL FERTILIZERS

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It has long been known that the action of phosphatic fertilizers is of short duration (14). Many authors (1, 2, 4, 6, 7, 12, 13) have studied the absorption or immobilization of phosphorus fertilizers when added to the soil, the availability of phosphorus absorbed by soil colloids (15), and the influence of $CO_2$, soil reaction, lime, and silica on the availability of rock phosphate or soil phosphorus (8, 9, 3, 11, 5). Few data are available, however, concerning the depression of phosphate availability by soil microorganisms or concerning the relation of time of application to depression of phosphate availability. This paper reports the results of experiments designed to study these two problems.

## EFFECT OF MICROORGANISMS ON PHOSPHATE AVAILABILITY

To pots 25 cm. in diameter and 40 cm. deep containing 25 kgm. of a soil low in phosphorus, 4 gm. of ammonium sulfate and progressively increasing quantities of $Na_2HPO_4$ were added. The sodium phosphate was applied in three ways: directly to the soil; dissolved and absorbed by straw (15 units of straw for each unit of $P_2O_5$), which was then added to the soil; and mixed with sulfate of ammonia (2 units of N for each unit of $P_2O_5$), dissolved, and absorbed by straw, which was then added to the soil. In the last case the sulfate of ammonia absorbed by the straw was substracted from the 4 gm. added directly to the pot. Wheat was grown in the pots.

Table 1 shows the grain yields obtained. These increased regularly with increasing quantities of $P_2O_5$ up to 96 mgm. The increment was higher when the phosphate was applied directly to the soil than when it had been absorbed by straw, and it was lowest when the straw had also absorbed nitrogen. The respective mean yields for these three methods of applying the O to 96 mgm. $P_2O_5$ were 22.6, 20.3, and 17.3 gm. On the other hand, with the larger applications (120 to 216 mgm. $P_2O_5$) there was no regular increase with increasing phosphorus, and the three methods of application gave about the same average yields: 29.3, 30.5, and 29.1 respectively.

The results indicate that the action of phosphate was depressed when the nutrient was absorbed by straw and was still more depressed when the straw had also absorbed nitrogen and thus been conditioned for activated decomposition. The decrease in yields cannot be ascribed to immobilization of nitrogen by the addition of straw, because, if this were so, the decrease ought to be greater with the larger applications of $P_2O_5$ and the corresponding larger additions of straw.

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### RELATION OF TIME OF APPLICATION TO PHOSPHATE AVAILABILITY

To study the relation of time of application to depression of phosphate availability, progressive applications (0, 0.04, 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, 0.40, and 0.44 gm. $P_2O_5$ per pot) of 46 per cent superphosphate were made to a low-phosphorus soil on August 3 and 17, September 2 and 17, October 3 and 18, and November 2 and 20. Wheat was sown in all pots on November 20. The yields showed a regular increase with increasing phosphorus, but the differences between the different dates of application were not significant.

In the experiment just outlined, the earliest application was made 2½ months before sowing, and no crop was grown in the meantime. The following experiment was therefore carried out to determine whether the interval between the application of phosphate and the sowing of a crop had any effect. To galvanized iron containers 22 cm. in diameter and 40 cm. deep filled with 25 kgm. of a red

TABLE 1

*Influence of addition of straw on availability of sodium phosphate as indicated by grain yields*

| P₂O₅ ADDED PER POT | GRAIN YIELDS | | |
| --- | --- | --- | --- |
| | No Straw | Straw | Straw and sulfate of ammonia |
| *mgm.* | *gm.* | *gm.* | *gm.* |
| 0 | 10.0 | 10.0 | 10.0 |
| 24 | 21.9 | 21.8 | 15.2 |
| 48 | 25.0 | 22.3 | 20.5 |
| 72 | 27.4 | 21.4 | 21.3 |
| 96 | 28.7 | 26.1 | 19.7 |
| 120 | 36.8 | 28.7 | 27.6 |
| 144 | 29.7 | 31.6 | 31.3 |
| 168 | 30.0 | 27.5 | 32.7 |
| 192 | 23.5· | 28.9 | · 29.9 |
| 216 | 26.6 | 35.7 | 24.0 |

soil low in phosphorus, progressive additions of 40 per cent superphosphate (0, 0.06, 0.12, 0.18, 0.24, 0.30, 0.36, 0.42, and 0.48 gm. $P_2O_5$ per pot) were made on different dates—November 15, 1941 and March 31, May 22, August 22, and November 28, 1942. The pots were cropped in series as follows: 1, sown with wheat; 2, sown with the legume *Ervum ervillia*; 3, fallowed; 4, sown with wheat for green manure; 5, sown with *E. ervillia* for green manure. A sixth series was also fallowed, but to the soil in each of these pots 15 gm. of chemically pure glucose was added at the time of phosphate application, except that the last addition of glucose was made 18 days after that of phosphate—on December 16 instead of November 28, 1942. The wheat and *E. ervillia* were sown on November 15, 1941. The plants winterkilled, however, and the remaining plants therefore were turned under. In series 1 and 2 the plants were turned under in March, 1942, and young plants were transplanted into the pots on March 28. In series 4 and 5 the plants were turned under May 18, 1942; on this date they were rather too lignified. Wheat was sown on all pots November 28, 1942, and

TABLE 2

*Grain yields\* of wheat fertilized on different dates, from 1 year before sowing to date of sowing, with different quantities of phosphate and with different cropping treatments† the preceding year*

| PHOS-PHATE ADDITION | Series 1 Date fertilized | | | | Series 2 Date fertilized | | | | Series 3 Date fertilized | | | | | Series 4 Fertilized 11/15-5/22 | Series 5 Fertilized 11/15-5/22 | Series 6 Date fertilized | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 11/15-3/31 | 11/15-5/22 | 3/31-8/22 | 5/22-8/22 | 11/15-3/31 | 11/15-5/22 | 3/31-8/22 | 5/22-8/22 | 11/15-3/31 | 11/15-5/22 | 3/31-8/22 | 5/22-8/22 | 8/22-11/28 | | | 11/15-3/31 | 11/15-5/22 | 3/31-8/22 | 5/22-8/22 | 5/22-11/28 |
| | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. |
| P0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.9 | 14.9 | 14.9 | 14.9 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 17.2 | 16.4 | 16.3 | 16.3 | 16.4 | 16.4 | 14.7 |
| P0-1 | 13.6 | 14.9 | 14.9 | 14.4 | 13.8 | 15.3 | 15.2 | 13.8 | 16.9 | 16.1 | 16.1 | 16.1 | 15.8 | 16.9 | 18.0 | 16.5 | 17.2 | 16.9 | 16.4 | 14.7 |
| P0-2 | 13.2 | 13.7 | 15.9 | 16.7 | 14.0 | 15.5 | 16.3 | 15.6 | 17.3 | 17.4 | 17.3 | 17.2 | 17.1 | 18.9 | 17.9 | 17.7 | 18.2 | 17.4 | 16.9 | 15.1 |
| P1-3 | 13.3 | 15.1 | 17.2 | 19.3 | 14.7 | 17.8 | 18.7 | 18.2 | 17.4 | 16.8 | 17.6 | 17.8 | 18.7 | 18.9 | 17.2 | 17.1 | 18.7 | 18.1 | 17.4 | 18.2 |
| P2-4 | 16.3 | 17.1 | 18.1 | 19.5 | 16.4 | 17.2 | 18.7 | 18.6 | 16.9 | 17.8 | 18.4 | 18.8 | 20.6 | 19.5 | 17.8 | 18.0 | 18.5 | 17.5 | 17.8 | 20.3 |
| P3-5 | 18.3 | 18.1 | 18.0 | 18.5 | 17.6 | 18.3 | 18.5 | 18.8 | 18.4 | 17.8 | 20.6 | 20.5 | 21.4 | 18.3 | 18.0 | 18.9 | 19.8 | 18.6 | 18.1 | 22.7 |
| P4-6 | 18.3 | 20.4 | 20.1 | 19.7 | 19.6 | 19.4 | 20.1 | 21.0 | 18.2 | 19.3 | 20.1 | 20.4 | 22.1 | 19.9 | 21.0 | 19.3 | 20.0 | 18.3 | 17.9 | 22.7 |
| P5-7 | 19.1 | 21.0 | 21.6 | 21.1 | 21.8 | 20.0 | 22.3 | 23.0 | 20.8 | 19.9 | 21.8 | 22.1 | 23.1 | 20.9 | 20.4 | 19.3 | 19.8 | 18.8 | 17.6 | 22.7 |
| P6-8 | 19.2 | 21.2 | 21.9 | 21.5 | 22.0 | 22.1 | 22.0 | 23.7 | 22.1 | 26.6 | 23.0 | 23.2 | 25.9 | 21.5 | 22.1 | 19.7 | 20.5 | 19.7 | 19.6 | 23.7 |
| P7-8 | 20.2 | 21.4 | 22.6 | 22.4 | 23.4 | 19.9 | 21.0 | 22.9 | 22.1 | 22.5 | 22.7 | 23.9 | 25.4 | 21.4 | 21.4 | 20.9 | 21.5 | 20.7 | 20.8 | 24.3 |
| P1-8 | 17.7 | 18.3 | 19.5 | 19.7 | 18.5 | 18.9 | 19.6 | 20.1 | 18.9 | 19.7 | 19.8 | 20.7 | 21.3 | 19.9 | 19.7 | 19.5 | 19.1 | 19.1 | 18.3 | 20.4 |

\* Moving averages calculated according to the author's (10) method. The yield tabulated at the intersection of P0-2 and 11/15-5/22, for example, is the average of the following combinations of phosphate addition and fertilization date: P0 3/31, P1 3/31, P2 3/31, P1 11/15, and P1 5/22; the yield tabulated at the intersection of P1-3 and 3/31-8/22 is the average of the following combinations of phosphate addition and fertilization date: P1 5/22, P2 5/22, P3 5/22, P2 3/31, and P2 5/22; and so on. The yield tabulated at the intersection of P0 and 11/15-3/31 is the average of the dates 11/15 and 3/31 with addition P0, and so on. The yield tabulated at the intersection of P1-8 and 11/15-3/31 is the average of additions P1, P2, ... P8 combined with fertilization dates 11/15 and 3/31, and so on.

† Series 1, wheat; series 2, *E. ervillia*; series 3, fallow; series 4, wheat for green manure; series 5, *E. ervillia* for green manure; series 6, fallow, glucose additions.

‡ P0 = 0 P₂O₅; P1 = 0.06 mgm. P₂O₅; P₂ = 0.12 mgm. P₂O₅, etc.

TABLE 3

*Grain yield of wheat and* Ervum ervillia *fertilized on different dates before and after transplanting on March 28*

| PHOSPHATE ADDITION* | WHEAT YIELD | | | E. ervillia YIELD | | |
|---|---|---|---|---|---|---|
| | Fertilized 11/15 | Fertilized 3/22 | Fertilized 5/22 | Fertilized 11/5 | Fertilized 3/22 | Fertilized 5/22 |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| P0 | 5.2 | 5.2 | 5.2 | 5.4 | 5.4 | 5.4 |
| P0-1 | 5.3 | 5.7 | 5.9 | 5.7 | 5.8 | 6.0 |
| P0-2 | 5.6 | 6.3 | 5.7 | 5.9 | 6.4 | 5.7 |
| P1-3 | 6.3 | 7.2 | 5.8 | 6.5 | 7.2 | 5.8 |
| P2-4 | 6.8 | 8.1 | 5.4 | 6.8 | 8.1 | 5.4 |
| P3-5 | 7.1 | 7.9 | 5.4 | 7.0 | 7.9 | 5.4 |
| P4-6 | 6.9 | 8.7 | 5.2 | 6.8 | 8.7 | 5.2 |
| P5-7 | 6.7 | 8.7 | 5.3 | 6.6 | 8.7 | 5.3 |
| P6-8 | 7.4 | 9.4 | 5.8 | 7.4 | 9.4 | 5.9 |
| P7-8 | 7.7 | 9.0 | 6.2 | 7.7 | 9.0 | 6.3 |

\* See footnotes \* and ‡, table 2.

during the ensuing crop year all pots were profusely fertilized with nitrogen. Table 2 shows the grain yields obtained.

The addition of phosphate increased the yield in all cases, and its effectiveness became greater as the date of its application approached the sowing date. The action of phosphate was depressed by the preceding crop of wheat (series 1) as compared to fallowing (series 3); the position of the legume (series 2) was intermediate. Sugar and green manure (series 6) depressed the yield with the larger applications of phosphate but not with the smaller.

The yields of the first year are also interesting (table 3). The phosphate application of March 22 (6 days before transplanting) was very effective in increasing the yields; that of November 15 (4½ months before transplanting) was much less effective; and that of May 22 (15 days after earing) was wholly ineffective.

<div align="center">SUMMARY AND CONCLUSIONS</div>

Phosphate dissolved in water and absorbed by straw was less effective in increasing the yield of wheat than when added directly to the soil. The effectiveness was still less when the straw had also absorbed sulfate of ammonia and thus been conditioned for activated decomposition.

Phosphate applications on different dates during the year preceding sowing were more effective in increasing yields of wheat, the nearer the date of application approached that of sowing. The effectiveness of phosphate was depressed by a preceding crop of wheat as compared with fallowing and to a lesser degree by a preceding legume crop. The addition of glucose and green manure reduced the effectiveness of the larger applications of phosphate but not that of the smaller.

From these data it may be concluded that microorganisms and crop residues play an important part in the immobilization of phosphorus mineral fertilizers.

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I

# ARSENATE-DISPLACEABLE PHOSPHATE IN LONG-FERTILIZED AND UNFERTILIZED PLOT SOILS[1]

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Phosphoric acid is one of the most important constituents of commercial fertilizers, and the amount applied in intensive farming often exceeds that removed in the harvested crops. A tendency for phosphoric acid accumulation in un-eroded fertilized soils, therefore, is to be expected. Heavier soils, in general, have such great fixing power for phosphate that the equilibrium concentration of $PO_4$ in the soil water is scarcely affected by the excess so accumulated. This fixed phosphate is not entirely unavailable to crops, but its rate of release may be so slow that continued application of a phosphatic fertilizer is profitable. These further additions probably produce a temporarily high concentration of dissolved phosphate in the soil water in the vicinity of plant roots, until such time as the fertilizer has been dispersed through the soil and the phosphoric acid has been fixed.

Fixation of the phosphoric acid anion by soil has been variously explained. Some have believed it to be simply precipitation by cations capable of forming difficultly soluble phosphates, for example, calcium and magnesium, whether circulating in solution, present in solid basic compounds in calcareous soils, or held on the exchange complex. Russell (20) inclined to this opinion. Fixation in noncalcareous or acid soils has been attributed to adsorption by hydrated sesquioxides, principally ferric (8). The older views have been summarized by Bradfield (4), who also mentioned the possibility of $PO_4$'s replacing OH, $SiO_3$, or other anions exposed on an aluminosilicate surface. More recent explanations on a physicochemical basis are those of Mattson (12), Pugh (13, 14), Ravikovitch (15, 16), and others. In their concept, phosphate anions can replace hydroxyls in an exchange complex, whether of silicate-sesquioxide, sesquioxide, or of humus nature, and thus also influence the cation-exchange properties. The mutual replaceability of phosphate and hydroxyl ions as a factor in phosphate fixation has been emphasized by Kelly and Midgley (11). Replacement of phosphate by citrate and oxalate anions was discussed by Russell and Prescott (19) long ago; more recently, the activity of fluoride in that respect was reported on by Dickman and Bray (7).

The first published references to exchangeability of soil phosphate and arsenate anions noted were in papers by Antoniani (1, 2), who cited similar observations on hydrated ferric oxides by Biltz (*Ber.* 37: 3138–3150) and by Pratolongo (*Staz. Sper. Agr. It.* 48: 1915) and on soils by De Dominicis (*Staz. Sper. Agr. It.* 47:

449). More recently, the general subject of anion exchange in soils was discussed by Dean and Rubins (5, 6, 18). As a result of the publication of these latter papers, it seemed advisable to present some of the results of similar studies made in this laboratory in 1931.

Antoniani's papers described equilibrium studies on very large samples of soil with dilute solutions of phosphate, arsenic acid, and sodium arsenate but, beyond a note that arsenic had been separated as the sulfide, few details were helpful in applying the reaction to soil testing. After trials of various means for precipitating, reducing, or volatilizing much arsenic acid with quantitative recovery of a little accompanying phosphoric acid, simple evaporation with hydrobromic acid was discovered to be easiest and most effective.[3] Unavailability of the most important reagents with satisfactory purity required investigation into means for preparing them. Much preliminary work was thus necessary before satisfactory tests could be applied to soils.

Samples of surface soil from the unlimed ends of plots of Section D, 5-year rotation fertility experiment at Wooster, taken in 1925, were selected for a trial to determine the possibilities of developing a simple test for available phosphoric acid in soil. These plots had been under experimental treatment for over 30 years prior to sampling, as outlined in table 3 and more fully described in a previous publication (23). The results of this work on arsenate-displaceable phosphate were not encouraging in respect to value as a test for need of phosphate fertilization. In a general way they were in line with the findings of other investigations of about that time (10, 12, 15, 16). It is believed, however, that the details of reagent purification and of analytical procedures may be of interest to others wishing to work along the same line.

### PURIFICATION OF REAGENTS

Rubins and Dean (18) have commented on the difficulty of obtaining pure arsenic and hydrobromic acids, both required in very large amounts relative to the phosphate to be determined. The author prepared arsenic acid from arsenious oxide purified to be practically antimony-free, thus:

*Purification of arsenious oxide.* To 150 gm. powdered white arsenic in a 1-liter boiling flask, add 525 ml. concentrated hydrochloric acid with continuous swirling to prevent caking prior to solution. Connect the flask by rubber stopper and 10-mm. diameter glass tubing to a vertically supported inverted Liebig condenser with inner tube of similar width. Let the expanded adapter end of the condenser tube dip beneath the surface of 800 ml. cold water in a beaker marked at 1200 ml. With cold water circulating in the condenser jacket, distill 400 ml. Coarse crystals of arsenious oxide separate in the end of the condenser tube and in the dilute hydrochloric acid in the beaker. Wash the crystals with cold water until practically chloride-free, and dry. About 60 gm. purified arsenious oxide should be obtained.

In this simple method of purification, both arsenic and antimony distill and condense as the trichlorides. The $AsCl_3$ hydrolyzes on contact with water and

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[3] Trial of hydrobromic acid for the purpose was suggested by a note in a paper by Roark and McDonnell (17), citing earlier use for reducing arsenate to the readily volatile $AsBr_3$.

As₂O₃ separates, whereas the much smaller amount of SbCl₃ remains in the strongly acid solution. The purification is thus somewhat similar in principle to that described by Foulk and Horton (9). Roark and McDonnell (17) found that distillation of antimony is prevented by cuprous chloride in the concentrated hydrochloric acid arsenical mixture. It is possible that an addition of metallic copper might improve the purification.

*Preparation of arsenic acid.* Put 25 ml. of water and 50 gm. arsenious oxide purified as described in a 1-liter Pyrex Erlenmeyer flask. Add not more than 10 ml. concentrated nitric acid and warm in the hood to start the reaction. Red fumes are evolved copiously, and constant swirling may be necessary to avoid foaming over. Add more nitric acid when the reaction slackens. Less than 50 ml. concentrated nitric acid should suffice to complete the oxidation of As₂O₃ to H₃AsO₄, recognized by complete solution and cessation of fuming. Boil down rapidly with swirling until the liquid becomes syrupy, then boil more carefully. As soon as crystals appear, cease heating. The acid should solidify quickly to a white porcelain-like mass filled with bubbles. Bake on the steam plate to expel nitric acid, cool, add 300 ml. water, and boil to obtain a clear solution. Cool and dilute to 500 ml. for $M$ orthoarsenic acid.

TABLE 1

*Arsenic acid-ammonium arsenate solutions at various pH*

| pH | 2 $N$ NH₄OH | pH | 2 $N$ NH₄OH |
|---|---|---|---|
| | *ml.* | | *ml.* |
| 1.3 | .... | 5.0 | 5.35 |
| 2.0 | 1.95 | 6.0 | 6.70 |
| 3.0 | 4.35 | 7.0 | 9.35 |
| 4.0 | 5.05 | 8.0 | 10.50 |

To prepare arsenic acid-ammonium arsenate solutions normal in respect to arsenate content and at the stated pH values, 2 $N$ ammonium hydroxide is added in the amounts shown in table 1 to 10.00 ml. $M$ H₃AsO₄ and the mixture diluted to 30 ml. The figures tabulated were obtained from readings on a curve plotted from pH determinations on a number of similar mixtures.

*Purification of hydrobromic acid.* Some lots of the reagent obtainable were badly contaminated by phosphoric acid. This impure acid was made phosphate-free by one redistillation with a trap to scrub the vapors and stop spray. Nearly all should be distilled, as the liquid in the flask at the end is the constant-boiling point (125°C.) acid containing 52 per cent HBr.

### COLORIMETRIC DETERMINATION OF PHOSPHATE

With reagents purified as described, the author had no difficulty in determining phosphate colorimetrically by several molybdenum blue methods; of those compared, the Benedict-Theis procedure (3) seemed preferable.

### Reagents

*Benedict-Theis molybdate solution.* Dissolve 20 gm. ammonia-free molybdic anhydride in 100 ml. of 5 per cent sodium hydroxide prepared from sodium. Shake continuously and

warm if necessary to aid solution. Dilute to 250 ml. and filter. To a portion sufficient for the day's use, add an equal volume of concentrated sulfuric acid and cool. The acidified solution should show but a faint tinge of blue.

*Sodium bisulfite-hydroquinone solution.* Dissolve 37.5 gm. sodium bisulfite in water and add the solution to 1.25 gm. hydroquinone in a 250-ml. volumetric flask. Shake until all is in solution and dilute to volume. If not clear after standing several days, filter.

*Phosphate standards.* Dissolve 1.9165 gm. dried monopotassium dihydrogen phosphate, and dilute to 1 liter with water previously shaken with toluene and filtered, to prevent growth of molds. Dilute 5.00 ml. of this stock solution to 100 ml. with plain distilled water for a working standard. Each milliliter of the latter corresponds to 50 pounds $P_2O_5$ to the acre 2 million pounds soil when the aliquot of extract taken represents 2 gm. soil and both sample and standard are diluted to the same volume for comparison.

### Extraction and determination of phosphoric acid displaced

To 30 ml. of extracting solution in a 50-ml. Erlenmeyer flask, add 6 gm. finely ground sample, stopper, and shake frequently for 45 minutes[4]. Filter on a dry fluted paper, pouring back until the filtrate is clear. Transfer two 10-ml. aliquots to similar flasks and evaporate. Add 1 ml. concentrated nitric and 3 ml. hydrochloric acids and evaporate again, and repeat with 5 ml. hydrochloric acid alone, and finally with 5 ml. hydrobromic acid. After the latter evaporation, cool the flask and add to the residue of salts 8 ml. of water and 1 ml. acidified molybdate solution. Shake until solution is complete, add 1 ml. of the sodium bisulfite-hydroquinone solution, stopper, and set in a boiling water bath for exactly 10 minutes. Cool quickly in running water. After cooling, the color is reasonably stable, but comparison with standards carried along with the set should not be unduly delayed. Use of a colorimetric curve as described by Yoe (24) is necessary for high accuracy without a range of standards.

#### RESULTS

In the first experiment with the methods described applied to soil, the effect of variation in pH of extracting solutions on the apparent exchange of arsenate and of acetate anions for phosphate, and recovery of a known amount of phosphate previously added to soil were determined. A 1930 sample of Wooster silt loam surface soil from the unlimed end of plot 24, Section D, of the 5-year rotation fertility experiment was used. This had received complete fertilizer with sulfate of ammonia for about 35 years prior to sampling and had become unproductive and very acid (pH 4.3). A portion was allowed to dry, after addition of standard phosphate solution equivalent to 50 pounds $P_2O_5$ to the acre, and was ground finely. Another portion of the original soil was ground in the same way, and extractions from the two were compared (table 2).

The data indicate minimum displacement of phosphate by arsenate at pH 4–5 and maximum at pH 7, the highest value tested. The trend in recovery of added phosphate, incomplete in every instance, was similar. The effect of variation in pH upon the displacement is in agreement with Hester's (10) finding that the isoelectric point of ferric phosphate is at about pH 4.4, where the colloid is most stable, with fewest free valences, and should show a minimum exchange capacity for cations. His data show a maximum in cation exchange at pH 7.6; conse-

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[4] The author made no extensive investigation of extraction procedures. Rubins and Dean (18), however, report that leaching is unsuitable and recommend heating for 1 hour in a boiling water bath for an approximate equilibrium in anion exchange. In one test, the author obtained less phosphate displaced by arsenate at pH 7 with 2 hours' continuous shaking than from an identical mixture shaken at intervals during 45 minutes.

quently this should be the region of minimum colloid stability and maximum release of phosphate anions.    These results point strongly to ferric phosphate as the fixation compound involved.    There appears to have been no exchange with acetate anion, as the figures are small and tend to decrease with increase in pH. There has been insignificant direct solvent effect of the hydrogen ion at pH 3.0. The experiment indicates a specific displacement of phosphate by arsenate but none by acetate anion, and a great influence of the hydrogen ion upon the former.

The marked increase in percentage recovery of added phosphate and in the absolute amounts of $P_2O_5$ removed by the arsenate solution at pH 7 over extraction at pH 5 is of interest.    These points are representative of heavily limed and

TABLE 2

*Phosphoric acid extracted from soil by N ammonium arsenate and acetate solutions*

| EXTRACTANT SOLUTION | DISPLACED BY ARSENATE SOLUTIONS | | | DISPLACED BY ACETATE SOLUTIONS | |
|---|---|---|---|---|---|
| | Original soil | Phosphated soil* | Recovery | Original soil | Phosphated soil* |
| *pH* | *lbs.* | *lbs.* | *per cent* | *lbs.* | *lbs.* |
| 2.0 | 230 | 240 | 20 | .. | .. |
| 3.0 | 130 | 145 | 30 | 11 | 10 |
| 4.0 | 90 | 100 | 20 | 26 | 10 |
| 5.0 | 90 | 110 | 40 | 10 | 9 |
| 6.0 | 180 | 215 | 70 | .. | .. |
| 7.0 | 340 | 375 | 70 | 6 | 6 |

* A standard solution of $KH_2PO_4$ equivalent to 50 pounds $P_2O_5$ per acre was added to 2 mm. soil in a dish, mixed thoroughly, and the mass allowed to dry at room temperature. This phosphated soil was then ground fine in a jar mill with flint pebbles, in the same manner as the original soil.

of unlimed acid soils in Ohio.    Further comparisons of extraction by ammonium arsenate solutions, with the same procedure and at pH 5 and 7, were made on samples taken in 1925 from other plots of the same section to obtain the data in table 3.

These data show differences consistent, to some extent, with the fertilization. The differences are not striking, however, in comparison with the absolute figures for plots probably never fertilized with phosphate and known not to have received any manure for at least 30 years.    In another respect, the differences are inconsistent with plot records.    Presumably, there has been greater removal of $P_2O_5$ from plots with complete fertilization and better utilization of the identical amounts applied to all these fertilized plots, yet they show greater contents of arsenate-displaceable phosphate.    If the latter is considered available, or potentially so with increase in pH from liming, the soil has not been exhausted by the heavier production, but improved.    Decreased erosion consequent upon the increased plant growth from better fertilization and the accompanying accumulation of organic matter from roots may be the explanation.    Data for organic carbon in the soils are included in table 3 and show the most organic matter in the soil of plots 11 and 12, completely fertilized.

As before, the arsenate solution at pH 7 was much more effective in displacing

phosphate from the soil; the extracts made therewith were a light straw color, whereas those made at pH 5 were virtually colorless. Since the organic phosphorus contents of 4 per cent ammonia extracts from similar soils have shown a direct relation to intensity of color (21, 22), the possibility that the increased $P_2O_5$ in the slightly colored extracts made at pH 7 may be associated with an increased extraction of organic phosphorus must be considered.

To test this possibility, a larger sample of the soil from plot 12 was shaken continuously for 2 hours with arsenate solution at pH 7 and in the same proportion. The clear filtered extract was considerably deeper in color than that made in a shorter time with intermittent shaking, but contained less phosphate—303 pounds $P_2O_5$ per acre. A large aliquot was precipitated with magnesia mixture in

TABLE 3

*Phosphate displaced by arsenate from plot soils, unfertilized and fertilized . ' years*

| PLOT NO. | FERTILIZATION EACH 5-YEAR ROTATION | | | $P_2O_5$ DISPLACED | | $P_2O_5$ AT pH 7, RELATIVE TOTAL | ORGANIC CARBON |
|---|---|---|---|---|---|---|---|
| | N in NaNO$_3$ | $P_2O_5$ in superphosphate | K$_2$O in KCl | At pH 5 | At pH 7 | | |
| | lbs. | lbs. | lbs. | lbs. | lbs. | per cent | per cent |
| 1 | ... | ... | ... | 95 | 280 | 16 | 0.77 |
| 2 | ... | 45 | ... | 115 | 360 | 19 | 0.79 |
| 3 | ... | ... | 130 | 79 | 245 | 15 | 0.75 |
| 4 | ... | ... | ... | 92 | 290 | 18 | 0.75 |
| 5 | 70 | ... | ... | 98 | 330 | 19 | 0.76 |
| 6 | 70 | 45 | ... | 101 | 320 | 17 | 0.79 |
| 7 | ... | ... | ... | 80 | 295 | 18 | 0.67 |
| 8 | ... | 45 | 130 | 120 | 395 | 21 | 0.75 |
| 9 | 70 | ... | 130 | 100 | 310 | 18 | 0.74 |
| 10 | ... | ... | ... | 97 | 300 | 18 | 0.68 |
| 11 | 70 | 45 | 130 | 128 | 410 | 19 | 0.80 |
| 12 | 105 | 45 | 130 | 210 | 590 | 27 | 0.84 |

minimum amount necessary for the arsenate and phosphate present, with excess ammonia, to avoid carrying down much of the organic matter with the precipitate. In addition, the mixture was frozen for maximum precipitation of inorganic phosphate. The heavy crystalline precipitate of magnesium-ammonium arsenate and phosphate was filtered off and washed with 4 per cent ammonia. It was then dissolved from the filter with very dilute hydrochloric acid and the solution digested warm for a time, to coagulate the slight amount of dark colored organic matter present, filtered on the same paper, and the latter thoroughly washed with acidulated water. The ammoniacal filtrate and washings were finally poured through the filter to dissolve the trace of humus thereon, evaporated to expel ammonia, the residue treated with aqua regia to decompose ammonium salts and organic matter, and phosphate determined in the colorless solution so obtained. Phosphate found was equivalent to 25 pounds $P_2O_5$ per acre. It is concluded that extraction of organic phosphorus from this soil by ammonium arsenate solution at pH 7 is negligible.

## DISCUSSION

The general similarity of phosphates and arsenates with respect to molecular structures and solubilities suggests that with favorable relations in respect to active masses there should be extensive replacement of each by the other. Both readily available phosphoric acid and that fixed by the soil in widely diffused form may possibly be displaceable by arsenate. Such phosphate may thus be distinguished from that which is segregated in mineral grains offering slight surface for root contact and resistant to soil solvents, although possibly attacked by acids in a laboratory examination. Determination of the displaceable phosphate is thus another means of studying the forms in which phosphorus occurs in soils, supplementing others designed for attack upon a definite fraction of the total phosphorus. A procedure based upon this principle seems to present some important advantages. The displacement of phosphate by arsenate can be carried out at any desired pH value over a range wider than that natural to soils. During the process, there should be less tendency toward the readsorption or precipitation of phosphoric acid following primary solution than is known to occur during dilute acid extractions. Further, if the pH value of the extractant does not exceed 8.4, the maximum to be expected in a limed humid soil under natural conditions, there should be less organic phosphorus taken into solution than would be likely with a strongly alkaline solvent.

The increase in displacement of phosphate with increase in pH of the arsenate extractant is in agreement with agronomic data indicating that liming increases the availability of the $P_2O_5$ native to the Wooster soil as well as that added in superphosphate. This is evidently to be attributed to the increase in pH rather than solely to the increased supply of available calcium and magnesium.

## SUMMARY

Analytical methods developed for extracting soils with arsenic acid-ammonium arsenate solutions in a range of pH values and data on phosphoric acid thus displaced from long-fertilized and unfertilized plot soils are presented. Soil from superphosphated plots was higher in arsenate-displaceable $P_2O_5$ than was unfertilized soil, but the differences were small compared with the absolute amounts displaced. Recoveries of a known addition of phosphate ranged between 20 and 70 per cent. These, as well as the absolute amounts displaced, were minimum at pH 4-5 and maximum at the highest value included, pH 7. Extraction with neutral ammonium arsenate displaced between 15 and 27 per cent of the total $P_2O_5$ in the soil. Only a small amount of organic matter was contained in the extracts, and the amount of phosphorus in organic combinations therein was shown to be negligible. The marked effect of pH upon the arsenate displacement is considered to be evidence that a ferric phosphate or similar complex may be present in the soil. There was no significant displacement of phosphate by the acetate anion, and the direct solvent effect of the hydrogen ion at pH 3 was slight. The results suggest that the observed effect of liming in increasing the utilization of the native soil $P_2O_5$ as well as that added in the form of superphosphate is largely from the increase in the pH value of the soil.

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# FACTORS AFFECTING FIXATION OF PHOSPHORUS IN SOILS AS DETERMINED WITH RADIOACTIVE PHOSPHORUS

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The problem of ascertaining and altering the availability of the phosphorus of phosphates added to a soil is as complex as it is important. In most soils a large amount of the soluble phosphorus of added phosphates is rather quickly converted to an insoluble state and becomes, for the most part, unavailable for plant growth. These processes of fixation vary in different soil types and are influenced by natural or induced changes that take place in a soil.

Most soils cause a soluble phosphate to be reverted or otherwise changed with the result that the phosphorus remains in that part of the soil profile in which it has been placed. Invariably, this has been found to be true in loams and clays, and since these comprise a large part of the arable lands, the concept of immobility of soil phosphates has been taken largely for granted. In a recent investigation (6) it was found that fine sandy soils, especially those of the southern flatwoods, permit an extensive movement of fertilizer phosphorus such as that of superphosphate. It appears that since this movement of phosphorus results in leaching and diffusion losses in some cases, the soil management phase of fertilizer phosphate practices should consider factors such as time of application in relation to crop growth and to the rainy season of the year.

These various problems connected with the use of fertilizer phosphate have caused investigators to employ every useful scientific method in their researches. One such method involves the use of radioactive phosphorus to trace quantitatively the solubility changes that take place in a phosphate when it is added to a soil. A previous paper (2) records how this isotope technique can be applied to soil as well as to plant research. In the procedure used, the dipping type tubes as obtained from the manufacturer will usually be light-sensitive. This necessitates putting the tube in a light-tight enclosure for the measurement. It is convenient to dilute the solutions so that the count does not exceed 500 per minute, which avoids the need for coincidence correction. The solutions are measured for sufficient time so that the probable error in counting will not exceed ±3 per cent, which is considered below the other experimental errors.

The present paper presents results with this technique on samples of the A horizons of several soils. With the exception of Gainesville loam fine sand and Hernando fine sand (table 1), these were taken from virgin areas in Florida where experimental pastures are to be established. Several of these soils were known

to be deficient in phosphorus. To determine their relative fixation powers for phosphorus, some experiments were conducted with them using Morgan's sodium acetate-acetic acid extractant (4).

Definite amounts of monopotassium phosphate were added to the sodium acetate-acetic acid solution together with a minute amount of radioactive phosphorus as disodium phosphate in water, 1 ml. of which was added to 1 liter of the extracting solution. The amount of radiophosphorus used per 50 ml. of solution varied from 0.02 to 0.2 $\gamma$, representing an activity of about 3 microcuries.

TABLE 1

*Mechanical composition of soils used in phosphate studies**

| SEPARATE | SOIL TYPES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gaines-ville loamy fine sand | Amite sandy loam | Norfolk loamy sand | Dunbar very fine sandy loam | Coxville clay | Bladen fine sandy loam | Plummer fine sand | Leon fine sand | Hernando fine sand |
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Clay............... | 10.3 | 12.9 | 6.0 | 10.4 | 34.7 | 17.9 | 1.2 | 0.9 | 2.1 |
| Fine silt........... | 1.4 | 0.7 | 0.2 | 0.4 | 6.3 | 0.0 | 0.4 | 0.4 | 1.3 |
| Coarse silt......... | 6.6 | 9.2 | 10.1 | 32.2 | 32.6 | 14.9 | 4.5 | 4.0 | 3.9 |
| Very fine sand...... | 17.4 | 14.0 | 16.2 | 42.2 | 14.0 | 19.6 | 11.8 | 9.8 | 12.2 |
| Fine sand.......... | 37.0 | 21.6 | 23.9 | 11.7 | 6.5 | 31.1 | 50.5 | 41.6 | 52.1 |
| Medium sand....... | 20.6 | 19.1 | 21.9 | 1.6 | 2.8 | 13.5 | 29.5 | 34.2 | 24.3 |
| Coarse sand........ | 6.3 | 17.8 | 17.2 | 0.9 | 2.5 | 2.3 | 2.0 | 8.6 | 4.0 |
| Fine gravel........ | 0.2 | 4.6 | 4.3 | 0.4 | 0.5 | 0.4 | 0.0 | 0.4 | 0.1 |
| Total............. | 99.8 | 99.9 | 99.8 | 99.8 | 99.9 | 99.7 | 99.9 | 99.9 | 100.0 |
| Solution loss..... | 5.5 | 5.3 | 3.4 | 4.0 | 8.9 | 4.4 | 1.7 | 3.2 | 1.7 |

* Analyses compiled under the direction of J. R. Henderson.

The soils were air-dried and passed through a 40-mesh sieve; 10 gm. were agitated in a mechanical shaker with 50 ml. of the sodium acetate-acetic acid solution that contained the inert and active phosphorus. Agitation of the soil, phosphate, and extracting solution was continued until equilibrium was established as shown by the amount of phosphate retained by the soil when the mixture was filtered.

When 150 p.p.m. of phosphorus as monopotassium phosphate were added in the extracting solution, the average retention following shaking for 30 minutes was 95 and 94 per cent of the retention resulting from 60 and 90 minutes of shaking, respectively. Comparable figures with 300 p.p.m. of added phosphorus were 92 and 85 per cent. In the present work a 30-minute extraction period was used and since the concentration of phosphorus was less than 300 p.p.m. in most cases, it is evident that the values are not more than 10 per cent lower than those obtainable by a 90-minute period of shaking.

Inasmuch as the isotope technique is fairly new in soils research, it was compared with the chemical method for phosphorus as determined with a photoelectric colorimeter. Both methods were employed on portions of the same

filtered extract. For the chemical method the amount of phosphorus in the nonphosphated soil was subtracted from that obtained after phosphate was added, whereas in the isotope technique the phosphorus recovered was found directly by measuring the associated radiophosphorus with a Geiger Müller counter. The last column of table 2 shows that the chemical method gave somewhat higher percentages of fixation, particularly for the sandy soils. The two methods agreed fairly closely for loam and clay soils.

TABLE 2

*Effect of method of drying soils, after wetting with a solution of $KH_2PO_4$, upon retention of phosphorus when extracted with sodium acetate-acetic acid solution; comparison of methods of analyses*

| SOILS | PERCENTAGE ASSOCIATED RADIOACTIVE PHOSPHORUS RETAINED | | | | | | | | | | COMPARISON OF ANALYSES FOR P AND P* | | |
| | P* only | P* plus 150 p.p.m. P | | | P* plus 300 p.p.m. P | | | P* plus 450 p.p.m. P | | | | | |
| | Air-dry | Air-dry | 40°C. | 100°C. | Air-dry | 40°C. | 100°C. | Air-dry | 40°C. | 100°C. | Range of difference | Av. diff. | Av. excess of P over P* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | *per cent* | *per cent* | *per cent* |
| Leon fine sand. | 53.0 | 34.0 | 31.6 | 37.0 | 37.0 | 29.0 | 42.0 | 31.6 | 26.0 | 27.0 | ±1.6 to ±11.5 | ±5.8 | 3.9 |
| Plummer fine sand....... | 79.0 | 74.0 | 71.0 | 71.0 | 63.0 | 66.0 | 71.0 | 57.9 | 55.0 | 58.0 | ±0.5 to ±5.8 | ±2.5 | 0.7 |
| Hernando fine sand....... | 86.0 | 79.5 | 78.0 | 82.1 | 78.1 | 76.0 | 78.0 | 71.0 | 68.0 | 75.0 | ±0.3 to ±6.4 | ±4.3 | 3.5 |
| Norfolk loamy sand....... | 90.8 | 92.1 | 89.0 | 91.3 | 90.1 | 90.8 | 87.6 | 86.0 | 86.3 | 87.0 | ±0.5 to ±7.8 | ±2.5 | 2.3 |
| Gainesville loamy fine sand....... | 96.0 | 94.7 | 96.0 | 96.0 | 93.4 | 95.0 | 95.6 | 92.6 | 93.0 | 95.8 | ±0.8 to ±6.3 | ±4.9 | 4.9 |
| Amite sandy loam....... | 96.6 | 95.0 | 96.8 | 92.4 | 93.4 | 93.7 | 95.8 | 91.3 | 92.7 | 93.0 | ±0.0 to ±3.4 | ±1.0 | 0.5 |
| Bladen fine sandy loam. | 88.0 | 92.9 | 93.0 | 91.6 | 93.7 | 87.6 | 93.2 | 92.6 | 92.9 | 92.0 | ±0.5 to ±4.0 | ±1.5 | 1.2 |
| Dunbar very fine sandy loam....... | 88.7 | 92.4 | 91.3 | 90.5 | 92.0 | 92.4 | 91.3 | 90.5 | 91.0 | 91.3 | ±0.0 to ±1.2 | ±0.9 | 0.2 |
| Coxville clay.. | 90.5 | 95.8 | 95.0 | 93.9 | 97.1 | 96.3 | 93.9 | 95.3 | 96.0 | 95.3 | ±0.0 to ±2.4 | ±0.8 | 0.4 |

P* refers to radioactive phosphorus.

## EFFECT OF METHOD OF DRYING UPON FIXATION

The effect of method of drying upon fixation was studied by adding 5-ml. portions of the monopotassium phosphate solution to several 10-gm. soil samples, which were then divided into three sets of two each. One set was allowed to become thoroughly air-dry at room temperature; another was dried to constant weight at 40°C. and the third at 100°C. When the phosphate was used at rates of 150, 300, and 450 p.p.m. of phosphorus in the soil, the percentages of phosphorus fixed by the soils were, on the average, the same irrespective of method

of drying (table 2). It may be observed that the average percentage of fixation decreased with increase in amount of phosphate used. The following experiment was set up for a further study of fixation capacity.

#### EFFECT OF AMOUNT OF PHOSPHATE ADDED UPON PERCENTAGE RETAINED

The retention or fixing power of a soil for phosphorus should be satisfied by the addition of a sufficient amount, and different types of soil should have different requirements in that respect. These points were investigated for the nine types of soil that represent the areas under study.

To a sodium acetate-acetic acid extracting solution containing radiophosphorus, monopotassium phosphate was added in amounts ranging from none to 450 p.p.m. of phosphorus. The soils were extracted with these solutions. The results, recorded in table 3, show that there was a progressive decrease in the

TABLE 3

*Retention by various soils of phosphorus of monopotassium phosphate added in increasing concentrations in sodium acetate-acetic acid solution*

Percentage associated radioactive phosphorus retained

| SOIL TYPES | 0 P ADDED | 50 P.P.M. P ADDED | 150 P.P.M. P ADDED | 300 P.P.M. P ADDED | 450 P.P.M. P ADDED | AVERAGE DECREASE |
|---|---|---|---|---|---|---|
| Leon fine sand...................... | 31.0 | 26.9 | 18.3 | 18.2 | 11.9 | 12.2 |
| Plummer fine sand.................. | 60.3 | 51.9 | 36.6 | 38.7 | 18.8 | 23.8 |
| Hernando fine sand................. | 58.2 | 48.0 | 38.7 | 27.1 | 14.7 | 26.1 |
| Norfolk loamy sand................. | 74.3 | 51.0 | 44.4 | 31.8 | 17.4 | 38.1 |
| Gainesville loamy fine sand.......... | 87.2 | 88.0 | 76.4 | 60.0 | 53.2 | 17.8 |
| Amite sandy loam................... | 89.3 | 81.7 | 70.6 | 57.6 | 49.4 | 24.5 |
| Bladen fine sandy loam.............. | 85.5 | 80.6 | 81.3 | 75.4 | 71.2 | 8.4 |
| Dunbar very fine sandy loam........ | 82.2 | 78.3 | 76.3 | 69.5 | 59.1 | 11.4 |
| Coxville clay........................ | 87.5 | 85.7 | 83.5 | 87.0 | 84.4 | 2.3 |

percentage retained with increasing amounts added. This decrease was greatest for the sands, less for the fine sandy loams, and still less for the clay. The last column shows that the average decrease in fixation for the four concentrations ranged from 38.1 per cent for Norfolk loamy sand to 2.3 per cent for Coxville clay, over the potential fixation power as shown with radiophosphorus only. For Leon fine sand the fixation capacity as well as its decrease was less than for Plummer fine sand and for Hernando fine sand. This fixation capacity of the soils, especially the loams and clays, is very high on the basis of the amounts of phosphate usually applied in fertilizer practice. Thus in terms of 20 per cent superphosphate applied on the basis of 2,000,000 pounds of soil per acre, the applications recorded in table 3 ranged from 1,145 pounds per acre to nine times that amount. It is remarkable that Coxville clay retained over 80 per cent of these large amounts of phosphorus. Though all the other soils used in this experiment had their fixation capacities satisfied to a greater or lesser degree, there was no decrease in that of Coxville clay over the explored range of phosphorus concentrations.

### INCREASE OF FIXATION OF PHOSPHORUS IN AN AIR-DRIED SOIL

In one experiment (table 2) the soils were air-dried after being moistened with the phosphate solutions preceding extraction; in another experiment (table 3) the phosphate was added in the extracting solution. Table 4 shows that air-drying caused a marked increase in the percentage of phosphorus fixed; also, this increase in percentage was greater as the amounts of phosphorus were increased from 150 to 450 p.p.m. in the soil. The average increase in fixation, as given in the last column, ranged from 58.2 per cent for Norfolk loamy sand to 11.1 per cent for Coxville clay. It may be noted that the loams fixed over 90 per cent of the heaviest application, while Coxville clay fixed over 95 per cent.

TABLE 4

*Comparison of phosphorus retained by soils when $KH_2PO_4$ was added to soil, air-dried before extraction, and when added in sodium acetate-acetic acid extracting solution*

Percentage associated radioactive phosphorus retained

| SOIL TYPE | 150 P.P.M. P ADDED | | 300 P.P.M. P ADDED | | 450 P.P.M. P ADDED | | INCREASE DUE TO DRYING | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | To soil, air-dried | In extracting solution | To soil, air-dried | In extracting solution | To soil, air-dried | In extracting solution | 150 p.p.m. P added | 300 p.p.m. P added | 450 p.p.m. P added | Average |
| Leon fine sand........ | 34.0 | 18.3 | 37.0 | 18.2 | 31.6 | 11.9 | 15.7 | 18.8 | 19.7 | 18.1 |
| Plummer fine sand.... | 74.0 | 36.6 | 63.0 | 38.7 | 57.9 | 18.8 | 37.4 | 24.3 | 39.1 | 33.6 |
| Hernando fine sand... | 79.5 | 38.7 | 78.1 | 27.1 | 71.0 | 14.7 | 40.8 | 51.0 | 56.3 | 49.4 |
| Norfolk loamy sand... | 92.1 | 44.4 | 90.1 | 31.8 | 86.0 | 17.4 | 47.7 | 58.3 | 68.6 | 58.2 |
| Gainesville loamy fine sand........... | 94.7 | 76.4 | 93.4 | 60.0 | 92.6 | 53.2 | 18.3 | 33.4 | 39.4 | 30.7 |
| Amite sandy loam.... | 93.4 | 70.6 | 92.4 | 57.6 | 91.3 | 49.4 | 22.8 | 34.8 | 41.9 | 33.2 |
| Bladen fine sandy loam............... | 92.9 | 81.3 | 93.7 | 75.4 | 92.6 | 71.2 | 11.6 | 18.3 | 21.4 | 17.1 |
| Dunbar very fine sandy loam......... | 92.4 | 76.3 | 92.0 | 69.5 | 90.5 | 59.1 | 16.1 | 22.5 | 31.4 | 23.3 |
| Coxville clay......... | 95.8 | 83.5 | 97.1 | 87.0 | 95.3 | 84.4 | 12.3 | 10.1 | 10.9 | 11.1 |

Field application of phosphate probably results in a fixation somewhere between that found when soils are thoroughly air-dried after phosphoration and when they are in equilibrium with a phosphorus solution. This is because the entire mass of soil in this field seldom becomes thoroughly air-dry. Moreover, the phosphate is seldom incorporated so completely with the soil under field conditions. None the less, the experiments indicate that the loam and clay soils of the type studied will continue to fix large amounts of phosphate even after many reapplications.

### RETENTION AGAINST WATER AND AGAINST SODIUM ACETATE-ACETIC ACID EXTRACTANT

The radiophosphorus technique was used to compare the extracting power of water with that of the sodium acetate-acetic acid solution. Water was chosen

as the reference extractant because it is the dissolving medium in a soil solution. Soil waters contain varying amounts of dissolved carbon dioxide depending upon source of supply from respiration of plant roots and of soil microorganisms.   The nine soils used in this experiment ranged in pH from 4.12 to 6.25.   Volk and Bell found (7) that water and water saturated with $CO_2$ had equal powers of extracting phosphorus from Norfolk loamy fine sand at pH 5.6 and that water had a lower extracting power when the pH was above 5.6; the carbonated water extracted slightly more phosphorus when the pH of the soil was lower.

Table 5 shows that appreciably more of the phosphorus was retained by Leon fine sand when the sodium acetate-acetic acid extractant was used.   There was little difference in the case of Plummer fine sand.   For the other seven

TABLE 5

*Relative amounts of phosphorus in solution, added to soils subsequently dried at 80°C, retained against extraction with water and with a sodium acetate-acetic acid*

Percentage associated radioactive phosphorus retained

| SOIL TYPE | 50 P.P.M. P ADDED | | 200 P.P.M. P ADDED | | EXCESS FOR SODIUM ACETATE-ACETIC ACID EXTRACTANT | | |
|---|---|---|---|---|---|---|---|
| | Sodium acetate-acetic acid | Water | Sodium acetate-acetic acid | Water | 50 p.p.m. P | 200 p.p.m. P | Average |
| Leon fine sand.................... | 31.3 | 26.0 | 34.2 | 15.5 | 5.3 | 18.7 | 12.0 |
| Plummer fine sand............... | 80.6 | 82.0 | 75.5 | 72.9 | −2.6 | 5.8 | 1.6 |
| Hernando fine sand.............. | 72.8 | 90.0 | 71.5 | 75.0 | −18.2 | −3.5 | −10.9 |
| Norfolk loamy sand.............. | 90.7 | 98.9 | 90.9 | 95.1 | −8.2 | −4.2 | −6.2 |
| Gainesville loamy fine sand....... | 90.3 | 100.0 | 93.7 | 97.1 | −9.7 | −3.4 | −6.6 |
| Amite sandy loam................ | 96.1 | 98.2 | 94.4 | 97.6 | −2.1 | −3.2 | −2.7 |
| Dunbar very fine sandy loam..... | 94.6 | 98.7 | 93.7 | 97.4 | −4.1 | −3.7 | −3.9 |
| Coxville clay.................... | 95.7 | 98.3 | 95.9 | 97.9 | −2.6 | −2.0 | −2.3 |

soils, retention was somewhat less for the extractant solution than for water extraction.   When it is considered that all except one of these soils retained well over 70 per cent of the phosphorus from either extractant, the recorded differences in extracting powers are of little significance.

### RELATION OF FIXATION TO PHYSICAL CHARACTERISTICS OF SOILS

In table 6 the nine types of soil are arranged in decreasing order of their clay contents.   With minor exceptions, the fixation capacities of these soils decrease in the same order, starting with 85.7 per cent for Coxville clay and dropping to 26.9 per cent for Leon fine sand.   The same general but less closely adhering relationship exists between the fine and coarse silt totals for the soils (table 1) and their capacities to fix phosphate.   The moisture equivalent values of these soils (table 6) also decrease with decrease in fixation capacity.   The organic matter content is in the same general relationship, but the pH values, ranging from 4.12 to 6.25, show no systematic variation with that of fixation.

It is thus apparent that the phosphate-fixation capacities of these soils are related to their clay content and that fixation can be estimated from a determination of either the clay or the associated moisture-holding capacity. Lack of correlation with the pH of these soils receives some explanation from experiments of Burd and Murphy (1) with a fine sandy loam soil, in which they found that kaolinite caused a marked increase in the phosphorus-fixing power of the soil in equilibrium solutions ranging from pH 3.5 to 6.5. The ability of a plant to obtain phosphorus from a soil in which it is fixed or adsorbed by clay would then depend upon an anion exchange, which would, in turn, be dependent upon the degree of saturation of the complex with respect to phosphorus. Murphy (5) found that soils with high fixing power contained clay which was kaolinic in character. His experiments showed that kaolinite had a higher fixation capacity for phosphate than other types of clay colloids. The high fixing power

TABLE 6

*Physical characteristics of soils in relation to their power to retain phosphorus of monopotassium phosphate*

| SOIL TYPE | P RETAINED* | CLAY CONTENT | FINE AND COARSE SILT | ORGANIC MATTER | MOISTURE EQUIVALENT | pH |
|---|---|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | |
| Coxville clay............................ | 85.7 | 34.7 | 38.9 | 8.9 | 33.3 | 4.20 |
| Bladen fine sandy loam.............. | 80.6 | 17.9 | 14.9 | 4.4 | 22.7 | 4.55 |
| Amite sandy loam.................... | 81.7 | 12.9 | 9.9 | 5.3 | 16.2 | 6.04 |
| Dunbar very fine sandy loam........ | 78.3 | 10.4 | 32.6 | 4.0 | 18.2 | 5.30 |
| Gainesville loamy fine sand.......... | 88.0 | 10.3 | 24.0 | 5.5 | 15.7 | 6.25 |
| Norfolk loamy sand................. | 51.0 | 6.0 | 10.3 | 3.4 | 7.3 | 5.05 |
| Hernando fine sand................. | 48.0 | 2.1 | 5.2 | 1.7 | 8.5 | 6.15 |
| Plummer fine sand.................. | 51.9 | 1.2 | 4.9 | 1.7 | 8.1 | 4.73 |
| Leon fine sand...................... | 26.9 | 0.9 | 4.2 | 3.2 | 6.4 | 4.12 |

* When in equilibrium with a sodium acetate-acetic acid solution containing 50 p.p.m. of phosphorus in the form of $KH_2PO_4$.

of the soils used in the experiments reported herein indicates that their clays are probably kaolinites.

### EXTENSION OF THE USE OF RADIOPHOSPHORUS IN SOIL RESEARCH

Experiments such as those recorded in this paper with a soluble sodium salt of radiophosphorus are of value for the exploration and better understanding of soil factors affecting fixation, or its converse, availability, of the phosphorus of the given soluble sodium phosphate. Fertilizer phosphates comprise mono-, di-, and tricalcium phosphates as well as combinations with elements such as iron, aluminum, and fluorine. The last element is particularly important, since it is present in virtually all natural phosphates and markedly reduces the solubility and availability of the phosphorus for plants. This effect of fluorine is most noticeable when the phosphate is used in a finely divided but natural state in soil applications. According to some recent experiments of McIntire (3)

a calcium fluorphosphate is formed when superphosphate containing fluorine is added to limed soils and, as such, is not available to plants.

Thus it appears that the research value of radiophosphorus can be considerably extended by incorporating it into phosphorus compounds simulating as closely as possible those of the naturally occurring phosphates that are used for fertilizer.

From some previously reported (6) crop work in small lysimeters, it is calculated that about 500 millicuries of radiophosphorus would be needed for soil treatments over about an acre and that that amount of the isotope would be sufficient to permit quantitative determinations in the soil and in plants grown on the soil over a period of 3 to 4 months. Radiophosphorus can now be readily and cheaply obtained in amounts sufficient to permit experiments of a magnitude such that phosphorus could be traced through the soil, plant, and animal. In view of the interactions that phosphorus is known to have with other elements, it would seem advisable to carry on experiments of that nature.

### SUMMARY

Water solutions of monopotassium phosphate plus radioactive phosphorus were added to nine contrasting types of soil, and samples were dried at room temperature, at 40°C., and at 100°C. The percentage of phosphorus retained against a sodium acetate-acetic acid extracting solution was the same irrespective of method of drying.

In sandy soils the chemical method of determinating extractable phosphorus gave values somewhat higher than those obtained with the isotope technique. The two methods were in close agreement for loam and clay soil types. The radioactive method was adopted as standard procedure, since it permits quantitative estimation of phosphorus independently of that previously in or added to the soil.

In equilibrium solutions of soil and sodium acetate-acetic acid extracting solutions containing soluble phosphate, there was a progressive decrease in percentage of phosphorus retained as the concentrations were increased through a range of 50 to 450 p.p.m. This decrease in fixing power was greatest in the sands and least in the loams and the clay. The maximum decrease of 51.3 per cent occurred in Norfolk loamy sand and the minimum of 2.1 per cent in Coxville clay.

When the soils were dried after addition of solutions of soluble phosphate, the percentage fixed was greater than when the phosphate was added in the extracting solution, the increases ranging from 58.2 per cent for Norfolk loamy sand to 11.1 per cent for Coxville clay.

Appreciably more of the phosphorus was retained by Leon fine sand when the sodium acetate-acetic acid extractant was used than when the extractant was water. The reverse was true for Hernando fine sand. There was little difference for the other soils, which were mostly sandy loams together with a clay type.

The fixation power of the soils for phosphorus against a dilute acid extractant is directly related to their clay contents. Thus Coxville clay containing 34.7 per cent clay fixed 85.7 per cent of the phosphorus in an equilibrium series in which Leon fine sand containing 0.9 per cent clay fixed 26.9 per cent of the phosphorus. The other seven soils were intermediate with respect to clay content and fixation power. Fixation varied directly with the moisture equivalent of the soils and to a lesser degree with their silt and organic matter contents, but there was no correlation with pH values.

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# MECHANICAL ANALYSIS OF SOILS BY MEANS OF A COMMON HYDROMETER[1]

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Received for publication June 27, 1947

Because of its simplicity and rapidity, the Bouyoucos hydrometer method of mechanical analysis of soils has been widely used for the approximate textural classification of soils and other similar materials. To meet the increasing demand for a conventional method for mechanical analysis of soils and the difficulty of importing the Bouyoucos hydrometer from America during wartime, an attempt was made by the authors to study the mechanical composition of soil by means of a common hydrometer.

## LITERATURE REVIEW

Methods of mechanical analysis depending upon the change of density of a soil suspension were devised by Robinson (11) and others independently in different ways. Robinson's pipette method has been approved internationally. An early account of the hydrometer method of Bouyoucos was published in 1927 (2). Many improvements were later made by the inventor. Keen (7) has said that the hydrometer method is not only empirical in nature but also qualitative, and that two points deserve special consideration: first, the density of the soil suspension is not uniform during the sedimentation; and second, the volume of the hydrometer bulb is too large and disturbs the fall of soil particles in the suspension. Olmstead (8) reached the same conclusions.

Richter (10) and Bouyoucos (4) have proposed different methods for calculation of temperature correction to the hydrometer readings. The influence of temperature on the falling velocity of soil particles in water was studied by Giacanin (6). Correction for particle size determined by the hydrometer method was proposed by Thoreen (13). Bouyoucos (3), Gerdel (5), Peele (9), and others have applied the hydrometer method to the aggregate analysis of soils.

## APPARATUS AND METHOD

The common hydrometer used in this investigation measures the density of liquid substances ranging from 1.000 to 1.200 gm. per milliliter. The total length of the hydrometer is 35 cm., and the total number of divisions on the hydrometer scale is 200. Each division, therefore, corresponds to a density difference of 0.001 gm. per milliliter. It was calculated, by assuming that the

density of soil particles is 2.65, that each division on the scale corresponds to a difference of 1.6077 gm. of soil in 1000 ml. of suspension at 15°C. if 5 ml. of 1 $N$ sodium oxalate solution and 50 gm. of soil sample were added to the suspension before bringing volume to 1 liter. The value 1.6077 resulted from the application of the Fisher-Odén equation, which may be stated as follows:

$$P_s = P_w + \frac{W}{L}\left(1 - \frac{P_w}{P_r}\right) \qquad (1)$$

in which $P_s$, $P_w$, and $P_r$ are the densities of suspension, of dispersion medium, and of soil, respectively, $W$ is the weight of suspended soil particles, and $L$ is the volume of suspension. If, to a mixture of 50 gm. of soil and an aqueous solution containing 0.3350 gm. of sodium oxalate, water is added so as to produce a total suspension volume of 1 liter at 15°C., equation (1) becomes (2) by assuming the density of soil equal to 2.65 gm. per milliliter.

$$P_s = 0.9994 + \frac{50}{1000}\left(1 - \frac{0.9994}{2.65}\right) = 1.0305 \text{ gm. per milliliter} \qquad (2)$$

The figure 0.9994 is obtained by adding the weight of sodium oxalate present in 1 ml. of suspension to the density of water at 15°C., thus:

$$0.9991 + \frac{0.3350}{1000} = 0.9994 \text{ gm. per milliliter.}$$

The number of divisions lying between 1.0305, the density of a soil suspension containing 50 gm. of soil per liter of suspension, and 0.9994, the density of the dispersion medium, may be calculated as follows:

$$(1.0305\text{--}0.9994)/0.001 = 31.1 \text{ divisions} \qquad (3)$$

Accordingly, one division on the scale corresponds to $\frac{50.00}{31.1} = 1.6077$ gm. of soil per liter of suspension.

The relationship between the reading of the hydrometer employed and the summation percentage of soil particles in suspension is given in table 1. The hydrometer used in this investigation was calibrated at 15°C.

If $h$ represents the hydrometer reading and $\Delta h$ the temperature correction, then the weight of soil suspended at the time of reading is equal to $(h + \Delta h) \times 1.6077$ gm. The necessary corrections to the hydrometer readings for temperatures of experimentation other than 15°C. are listed in table 2. The method of computing the temperature correction is exactly the same as that given by Bodman (1).

In making mechanical analyses with the common hydrometer, Bouyoucos' method was followed exactly. For convenience, the following abbreviations are used when referring to the various methods of mechanical analysis in this investigation:

Pipette method (P): pipette method of G. W. Robinson.
Bouyoucos' hydrometer method (B): original Bouyoucos method.

Common hydrometer method (C): common hydrometer used in place of Bouyoucos' hydrometer; other analytical procedures the same.

TABLE 1

*Cumulative percentage of suspended soil particles corresponding to given density reading of the common hydrometer employed*

Calculations based on temperature of 15°C.

| SUSPENSION DENSITY | PER CENT | SUSPENSION DENSITY | PER CENT | SUSPENSION DENSITY | PER CENT | SUSPENSION DENSITY | PER CENT |
|---|---|---|---|---|---|---|---|
| 1.0000 | 1.92 | 1.0075 | 26.04 | 1.0150 | 50.16 | 1.0230 | 75.88 |
| 1.0005 | 3.52 | 1.0080 | 27.64 | 1.0155 | 51.76 | 1.0235 | 77.48 |
| 1.0010 | 5.14 | 1.0085 | 29.26 | 1.0160 | 53.36 | 1.0240 | 79.08 |
| 1.0015 | 6.74 | 1.0090 | 30.86 | 1.0165 | 54.98 | 1.0245 | 80.70 |
| 1.0020 | 8.36 | 1.0095 | 32.46 | 1.0170 | 56.58 | 1.0250 | 82.30 |
| 1.0025 | 9.96 | 1.0100 | 34.08 | 1.0175 | 58.18 | 1.0255 | 83.92 |
| 1.0030 | 11.56 | 1.0105 | 35.68 | 1.0180 | 59.80 | 1.0260 | 85.52 |
| 1.0035 | 13.18 | 1.0110 | 37.28 | 1.0185 | 61.40 | 1.0265 | 87.12 |
| 1.0040 | 14.78 | 1.0115 | 39.90 | 1.0190 | 63.02 | 1.0270 | 88.74 |
| 1.0045 | 16.38 | 1.0120 | 40.50 | 1.0195 | 64.62 | 1.0275 | 90.34 |
| 1.0050 | 18.00 | 1.0125 | 42.12 | 1.0200 | 66.22 | 1.0280 | 91.96 |
| 1.0055 | 19.60 | 1.0130 | 43.72 | 1.0205 | 67.84 | 1.0285 | 93.56 |
| 1.0060 | 21.22 | 1.0135 | 45.32 | 1.0210 | 69.44 | 1.0290 | 95.16 |
| 1.0065 | 22.82 | 1.0140 | 46.94 | 1.0215 | 71.06 | 1.0295 | 96.78 |
| 1.0070 | 24.42 | 1.0145 | 48.54 | 1.0220 | 72.66 | 1.0300 | 98.38 |
|  |  |  |  | 1.0225 | 74.26 | 1.0305 | 100.00 |

TABLE 2

*Temperature correction for the common hydrometer*

| TEMPERATURE OF SUSPENSION | ABSOLUTE DENSITY OF WATER | DIFFERENCE FROM DENSITY AT 15°C. | TEMPERATURE CORRECTION (AS NUMBER OF DIVISIONS ON HYDROMETER SCALE TO BE ADDED OR SUBTRACTED FROM READING) |
|---|---|---|---|
| °C. | gm./ml. | gm/ml. |  |
| 5 | 1.0000 | 0.0009 | −0.9 |
| 7 | 0.9999 | 0.0008 | −0.8 |
| 9 | 0.9998 | 0.0007 | −0.7 |
| 11 | 0.9996 | 0.0005 | −0.5 |
| 13 | 0.9994 | 0.0003 | −0.3 |
| 15 | 0.9991 | ...... | ..... |
| 17 | 0.9988 | 0.0003 | +0.3 |
| 19 | 0.9984 | 0.0007 | +0.7 |
| 21 | 0.9980 | 0.0011 | +1.1 |
| 23 | 0.9976 | 0.0015 | +1.5 |
| 25 | 0.9971 | 0.0020 | +2.0 |
| 27 | 0.9965 | 0.0026 | +2.6 |
| 29 | 0.9960 | 0.0031 | +3.1 |

Modified common hydrometer method (M): the common hydrometer method with some modification in analytical procedure.

## EXPERIMENTAL

### *Precision of common hydrometer method*

To ascertain the reliability of the common hydrometer method, soils were analyzed by the pipette method, Bouyoucos' method, and the common hydrometer method. The results obtained, together with their coefficients of variability of standard deviation, are listed in table 3.

The data reveal that the common hydrometer method gave fairly consistent results, although results obtained with Bouyoucos' hydrometer method agreed more closely with those obtained by the pipette method. The fairly satisfactory

TABLE 3

*Coefficient of variability obtained with the pipette, the Buoyoucos, and the common hydrometer methods (soil 8)*

| METHOD | PARTICLE SIZE RANGE | PERCENTAGE BY WEIGHT | | | | | STANDARD DEVIATION | COEFFICIENT OF VARIABILITY OF STANDARD DEVIATION |
|---|---|---|---|---|---|---|---|---|
| | | Replications | | | | Mean | | |
| | | 1 | 2 | 3 | 4 | | | |
| | $\mu$ | | | | | | | *per cent* |
| Pipette | <2 | 62.97 | 63.31 | 63.18 | 63.06 | 63.13 | 0.15 | 0.238 |
| | 5–2 | 2.70 | 3.55 | 2.91 | 2.92 | 3.02 | 0.37 | 12.251 |
| | 50–5 | 20.53 | 20.14 | 20.41 | 20.92 | 20.50 | 0.32 | 1.561 |
| | >50 | 13.80 | 13.00 | 13.50 | 13.10 | 13.35 | 0.37 | 2.772 |
| Bouyoucos | <2 | 62.81 | 61.45 | 62.51 | 63.59 | 62.59 | 0.89 | 1.422 |
| | 5–2 | 6.07 | 7.53 | 5.20 | 4.12 | 5.73 | 1.44 | 25.131 |
| | 50–5 | 27.01 | 26.61 | 27.88 | 27.88 | 27.34 | 0.64 | 2.341 |
| | >50 | 4.11 | 4.41 | 4.41 | 4.41 | 4.33 | 0.18 | 4.157 |
| Common hydrometer | <2 | 58.23 | 59.35 | 59.55 | 60.85 | 59.49 | 1.07 | 1.799 |
| | 5–2 | 3.31 | 3.19 | 2.99 | 3.07 | 3.14 | 0.14 | 4.459 |
| | 50–5 | 13.63 | 12.63 | 15.50 | 13.64 | 13.85 | 1.20 | 8.643 |
| | >50 | 24.83 | 24.83 | 21.96 | 22.44 | 23.52 | 1.53 | 6.507 |

result obtained by the common hydrometer method may be attributed to the fact that the bulb of the Bouyoucos hydrometer which was used occupies a volume of 65–70 ml. whereas that of the common hydrometer occupies only 30–35 ml. The greater volume of the bulb of the Bouyoucos hydrometer may cause greater disturbance of soil particles in suspension when the hydrometer is lowered into the suspension. It may be noticed also that the length of the Bouyoucos hydrometer is 28 cm. and the distance between the zero and fiftieth graduation is 8.7 cm., which corresponds to nearly one third the total length. The total length of the common hydrometer is 35 cm., and the distance between zero and the fiftieth division is only 3.1 cm., or only about one tenth the total length. Although this means a smaller degree of sensitivity for the common hydrometer, the difference of density reading may be smaller.

*Limitation of use*

The data of table 3 and the lower sensitivity of the common hydrometer may suggest unreliability of this method in dilute suspensions by comparison with the Bouyoucos hydrometer method. To ascertain the suitable range of suspension concentration within which the measurement by common hydrometer could be satisfactorily performed, suspensions of different concentrations were prepared from the same soil and analyzed by the common hydrometer in replicated trials. The coefficient of variability was also computed for comparison. It was observed that in case a silt plus clay content in the sample is less than 20 gm., that is, for soils which have a sand content greater than 60 per cent, the common hydrometer cannot provide a consistent duplicable result.

*Comparison between common hydrometer and pipette methods in clay suspensions of various concentrations*

From table 3 it may be seen that discrepancies between the results obtained by pipette and common hydrometer do exist. These may be due mainly to the existence of the density gradient in the soil suspension which has different effects upon the density measurement by the two methods.

It may be further noticed that differences exist between the two methods in the time of reading density or sampling the suspension. Also, there are differences in the depth of measuring the density of suspension.

The presence of a gradient in suspension density during sedimentation is unavoidable. To ascertain whether the common hydrometer method will give a result as accurate as that obtained by the pipette method in case no such density gradient is present, the authors have used homogeneous clay suspensions of various concentrations. Measurements of the density were made by both pipette and common hydrometer methods at the beginning of settling. The results of this experiment revealed that the two methods gave very close agreement when no density gradient was present in the suspension. But in practice, such gradient in suspension density does occur. The best way, therefore, is to modify the time of density reading and the depth of sampling.

*Modification of time of reading density*

Modification of the time of reading density was made as the result of an experiment of the following design:

First, a few soils were analyzed by the common hydrometer, the Bouyoucos hydrometer, and the pipette methods. The results, together with those obtained by the modified procedure, are given in table 4.

According to the data for soil 4, for example, the clay content determined by the pipette method is 58.12 per cent. If 50 gm. of this soil were made up to 1 liter of suspension with sodium oxalate as dispersing agent, the density of this suspension due to the clay fraction, calculated from the Fisher-Odén equation, would be:

$$0.9994 + \frac{29.06}{1000}\left(1 - \frac{0.9994}{2.65}\right) = 1.0175 \text{ (see table 1)}.$$

This density value, obtained after necessary temperature correction from the original hydrometer reading, evidently permits calculation of the clay content. The amount of clay calculated in this way should be in agreement with that obtained by the pipette method.

In the foregoing equation the temperature is 15°C., and the real density of particles is assumed to be 2.65. Since the measurements of soil density by common hydrometer were made at 22°C. and 26°C., respectively, the densities

TABLE 4

*Mechanical analysis of soils by the pipette, Bouyoucos hydrometer, common hydrometer, and modified common hydrometer methods\**

| SOIL NUMBER | <50 μ | | | | <5 μ | | | | <2 μ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | M | P | B | C | M | P | B | C | M | P | B |
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| 1 | 82.47 | 79.68 | 81.00 | 82.31 | 41.92 | 36.16 | 37.26 | 36.24 | 27.02 | 24.96 | 21.81 | 24.61 |
| 2 | 83.43 | 55.36 | 53.74 | 56.84 | 21.47 | 16.96 | 15.37 | 18.37 | 26.79 | 10.56 | 10.87 | 11.02 |
| 3 | 73.28 | 72.96 | 78.44 | 75.42 | 40.68 | 37.36 | 36.57 | 37.21 | 36.01 | 32.96 | 28.05 | 30.67 |
| 4 | 86.72 | 89.28 | 90.55 | 87.45 | 63.69 | 57.28 | 58.12 | 60.01 | 52.85 | 44.12 | 44.22 | 45.08 |
| 5 | 53.85 | 48.96 | 52.02 | 50.64 | 26.43 | 18.56 | 15.81 | 19.71 | 18.27 | 12.16 | 10.20 | 11.97 |
| 6 | 57.68 | 50.88 | 54.59 | 56.59 | 33.28 | 24.32 | 24.72 | 26.12 | 25.04 | 16.96 | 12.87 | 14.76 |
| 7 | 68.88 | 70.08 | 71.92 | 70.97 | 47.37 | 41.92 | 41.47 | 43.46 | 42.32 | 29.79 | 28.35 | 28.64 |

\* C = common hydrometer method; M = modified common hydrometer method; P pipette method; B = Bouyoucos method.

TABLE 5

*Times of reading for the common hydrometer*

| FRACTION | SIZE | TIMES OF READING AND METHOD OF COMPUTING: | |
|---|---|---|---|
| | | Bouyoucos hydrometer | Common hydrometer |
| | *mm.* | | |
| Combined sands | 2.0–0.05 | By difference | By difference |
| Silt | 0.05–0.005 | 40 seconds, then subtract clay | 60 seconds, then subtract clay |
| "Clay" | Finer than 0.005 | 1 hour | 100 minutes |
| Clay | Finer than 0.002 | 2 hours | 10 hours |

of the suspension at the temperatures of measurements must be corrected as follows:

$$\text{at } 22°C. \quad 1.0175 - 0.0013 = 1.0162 \tag{4}$$

$$\text{at } 26°C. \quad 1.0175 - 0.0023 = 1.0152 \tag{5}$$

Measurements of the density of the same soil suspension were made at various intervals from the very beginning of sedimentation to determine the time when the density of soil suspension as measured by the common hydrometer would give a result in agreement with those in equations (4) and (5). It was found that 100 minutes is the proper time interval for the determination of clay.

By the same procedure, the times of reading for particles less than 50 $\mu$ and less than 2 $\mu$ were found to be 60 seconds and 10 hours, respectively. The appropriate times of reading thus determined are given in table 5.

To ascertain whether the modified times found here are good for general use, mechanical analyses were made of several soils with the common hydrometer, using these modified times of reading. The results are listed in table 4 under the heading of modified common hydrometer method.
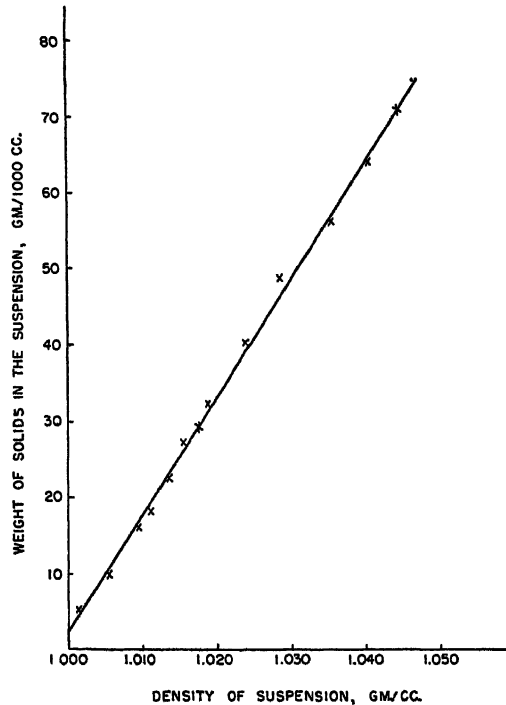


FIG. 1. DENSITY READING OF COMMON HYDROMETER IN RELATION TO WEIGHT OF SOLIDS (<5$\mu$) IN SUSPENSION

It is of interest to note that the figures given by the modified procedure of the common hydrometer method agreed more closely with the results given by the pipette method. The agreement is even closer than with the Bouyoucos method.

DISCUSSION

*Density determined by common hydrometer and the concentration of clay suspension*

If the common hydrometer method is valid for the mechanical analysis of soil, each reading on the common hydrometer scale should correspond to a certain concentration of the soil suspension. In other words, there would exist a linear relationship between the common hydrometer reading and the concentration of soil or of other similar suspended materials. Figure 1 contains data plotted

from the measurements made relating the density readings of the common hydrometer to the weight of suspended solids of diameter greater than 5 $\mu$. The figure indicates that an equation for the experimental relationship between these two values can be represented by a straight line.

### Effective particle diameter when analysis is made by modified common hydrometer method

A depth factor 0.42 (13) has been used for the correction of particle size when Bouyoucos' hydrometer is used. When the modification of the time of reading density is made, however, a new depth factor should be derived. When the pipette method is regarded as the standard method, the settling depths of 50, 5, and 2 $\mu$ particles, respectively, at modified reading times of 60 seconds, 100 minutes, and 10 hours, may be calculated as follows:

Settling depth for  2 $\mu$ particles:
$$S_{2\mu}: 600 \text{ minutes} = 10 \text{ cm.}: 457 \text{ minutes}; S_{2\mu} = 13.1 \text{ cm.}$$
Settling depth for  5 $\mu$ particles:
$$S_{5\mu}: 100 \text{ minutes} = 10 \text{ cm.}: 73 \text{ minutes}; S_{5\mu} = 13.7 \text{ cm.}$$
Settling depth for 50 $\mu$ particles:
$$S_{50\mu}: 1 \text{ minute} = 10 \text{ cm.}: 0.73 \text{ minutes}; S_{50\mu} = 13.7 \text{ cm.}$$

The times of sampling for the pipette method at 22°C. and a depth of 10 cm. are 457 minutes, 73 minutes, and 44 seconds. These calculations are based on the Stokes' equation that time of settling is proportional to depth of sedimentation when diameter and density of particles are unchanged.

On the average, the length of the immersed part of the common hydrometer employed in the present investigation is 30.7 cm. Dividing the average depth calculated, 13.5 cm., by 30.7 cm. gives a factor 0.44. It may be noticed that the factor 0.44 is in close agreement with that proposed by Thoreen (13). It may be applied to the common hydrometer when modification is made in the time of reading density. To learn the particle size corresponding to the hydrometer reading after a definite time of sedimentation, a graph of the particle size and hydrometer reading may be prepared by using this factor.

### Agreement between results by common hydrometer method and by pipette and Bouyoucos methods

Since the summation percentage of particles below a certain size represents a definite point on the summation curve proposed by Robinson (12), it may be expected that the figures given by the various methods used in the present investigation will differ. On the other hand, if the measurements obtained by the different methods with a given soil are used to plot summation curves, then the different curves should coincide in position, provided all methods are equally reliable.

The data of table 4 and their respective particle sizes are plotted in figure 2 for comparison of the results of analysis.

It will be seen that the curves for the seven soils so far analyzed by the modified common hydrometer method agreed in most cases with those which represent

analyses by the pipette method. This indicates that the common hydrometer may be used for approximate texture classification after the slight modifications are made in the times of reading density. ·

As early as 1928, Keen (7) asserted that the hydrometer method, by its very nature, can be only an empirical method. The authors have felt in undertaking this investigation that something of precision of theory and experiment may
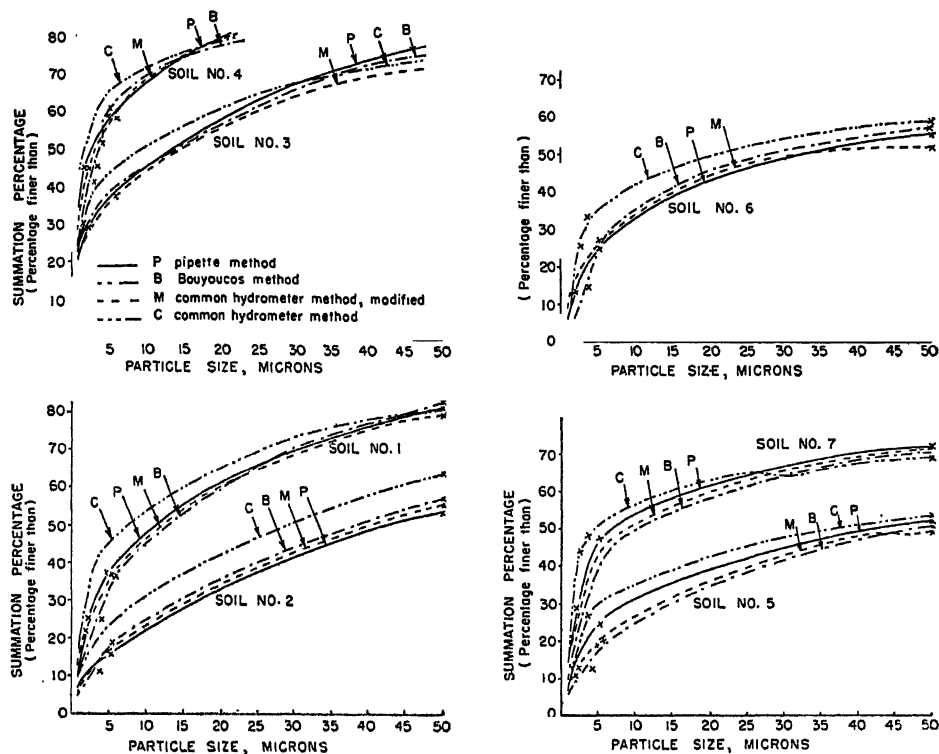


FIG. 2. SUMMATION PERCENTAGE CURVES REPRESENTING ANALYSES BY THE DIFFERENT METHODS

be added to the hydrometer method by checking it with the standardized pipette method.

## SUMMARY

It was found that if modification is made in the time of reading suspension density, the common hydrometer method can be used in mechanical analysis of soils where a reasonable degree of accuracy is desired.

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# APPARATUS FOR COLLECTING UNDISTURBED SOIL SAMPLES[1]

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Received for publication July 25, 1947

Two devices have been made for collecting undisturbed soil samples for porosity, volume weight, and permeability determinations. The first device is described diagrammatically in figure 1. It consists of a cylinder into which small cans are fitted, but with about ¾ inch of the open end of the can exposed. This exposed part of the can serves as the cutting edge. A piston is used, as shown, for pushing out the full cans. A washer-type ring is welded around the outside, flush with the bottom of the piston.[3] In sampling, when this ring touches the soil surface the can is full. The handle is ½-inch pipe and can be made any desired length. The cans used are of seamless tin, 2¾ inches in diameter and 1⅝ inches high.[4] A small air hole is drilled in the bottom of each.

The sampling operation consists of smoothing the surface, pushing the sampler into the soil until the ring touches the surface, spading the device out with a small hand garden spade, cutting the exposed surface smooth with a knife, and covering with the can lid. The entire operation for one sample requires only about a minute. Pore size distribution measurements may be made on these samples by the Leamer-Shaw[5] method. The total porosity and volume weight can be derived from the dry weight of the samples.

On some of the soils being studied in connection with a drainage project it was desirable to make permeability determinations. The can samples were not satisfactory for this. Therefore, another sampler was made in which cylinders were used instead of cans. This apparatus, shown in figure 2, is similar to the one described above. It has the same type handle, with piston, but has a different arrangement for holding the cylinder and has a removeable cutting edge.

The cylinder, shown in the middle of figure 2, fits tightly into the holder and against the piston head. The cutting edge fits tightly on the holder and has an offset on the inside of sufficient thickness to be flush with the inside of the cylinder when in place. The cutting edge is of hardened steel and can be replaced separately.

The cylinders are cut from seamless, stainless steel pipe. They are 2⅜ inches outside diameter and, therefore, the can lids described above fit them. They have a wall thickness of $\frac{1}{16}$ inch and a length of 1.53 inches. The apparatus

was made to hold cylinders of this length so that the cylinder volume would be 100 cc.
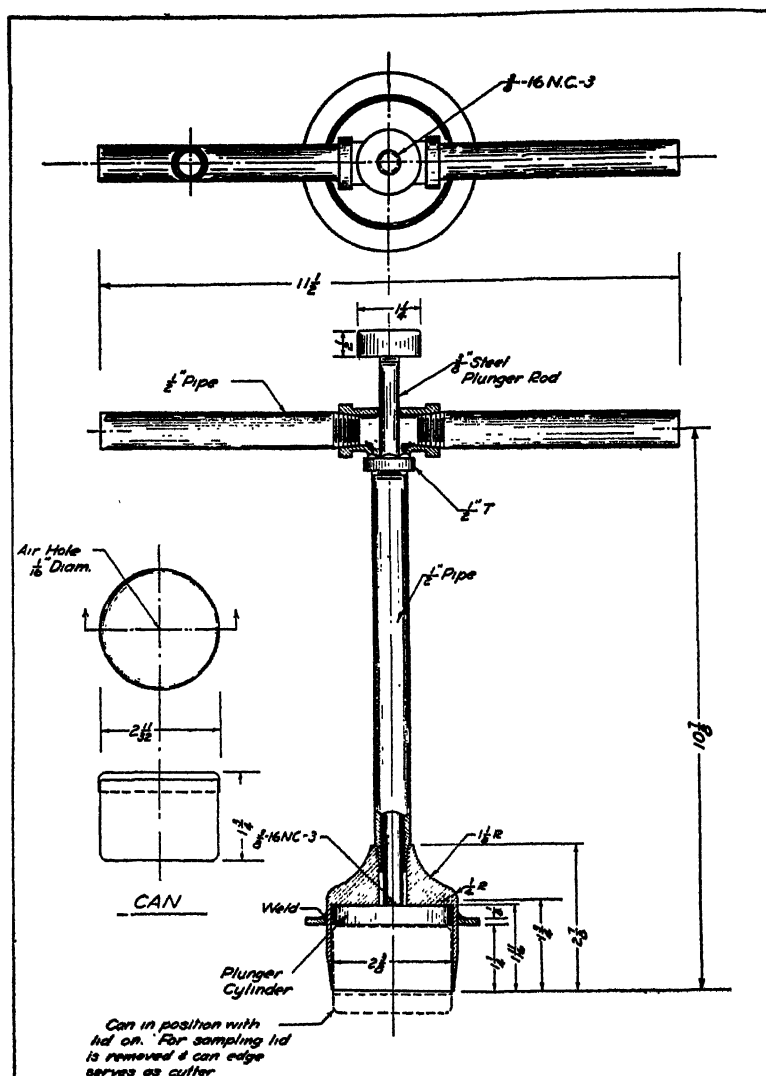


FIG. 1. APPARATUS FOR HOLDING CANS

Shown with a can (with lid on) in place.   Notice that the can extends beyond the holder, thus making the can the cutting part.

The use of stainless steel cylinders instead of cans offers several advantages: (a) The samples can be used for permeability measurements in addition to porosity and volume weight determinations; (b) the cylinders do not rust; (c) it is possible to see whether the cylinders are full—that is, whether any packing

occurred; (*d*) it is easier to saturate the soil with water for the pore-size distribution measurements; and (*e*) there is less danger of distortion of the rigid cylinders than of the cans. A possible disadvantage is the high cost of the stainless steel pipe.
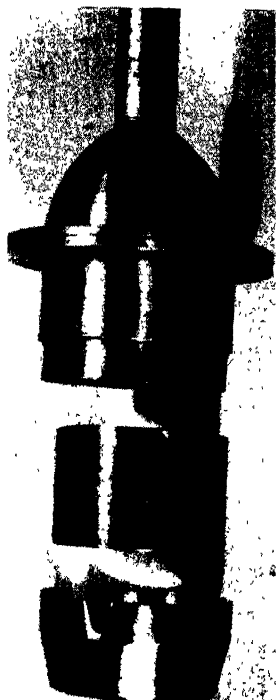


FIG. 2. APPARATUS FOR HOLDING CYLINDERS

The cylinder (middle) fits into the head (upper), and the cutting edge (bottom) is attached. The sample is removed by spading the apparatus out of the soil, removing the cutting edge, cutting the exposed surface smooth, covering with a can lid, pushing the cylinder out with the piston and covering the other end with a can lid.

Both can and cylinder samples have been taken from Piedmont and Coastal Plain soils of widely varying properties. The only difficulty encountered has been with one area of very gravelly soil, and by selection of sites even this field was sampled.

Many of the difficulties of taking larger samples are eliminated by the use of small cans or cylinders. The small variation in data among samples from the same plot and the differences exhibited between plots of different treatments indicate that the apparatus will be very useful in soil physics investigations.

# INVESTIGATIONS ON THE SEPARATION
## OF URONIDES FROM SOILS[1]

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Received for publication June 16, 1947

The presence of uronic substances in soil organic matter seems to be well established, and evidence has been presented indicating that the uronides are of microbial origin (2). The characteristics of the soil uronides have been meagerly investigated, and the nature of their association with the nonuronic soil constituents is still not known. Although numerous methods for extracting organic matter from soils have been suggested, none has been developed for the specific purpose of isolating the uronides or for determining their relationship to other carbon constituents.

Martin (3) has suggested that the persistence of the uronides in soil is due to their association or union with other soil constituents. This suggestion was based on the observation that isolated bacterial polyuronides exerted an aggregating influence on clay and silt particles. The stabilization of uronides, however, is not necessarily dependent upon the presence of inorganic colloids, since uronic substances accumulate in organic composts as well as in soils (1). The possibilities have been offered that the uronic groups are stabilized either by association with some other organic groupings or because they are microbial products of poor availability (4). If the uronic constituents in soils are not associated with the other organic constituents, their isolation from soil should not be difficult.

This paper reports attempts to separate uronides from other soil constituents with various solutions and the characteristics of the extracted and nonextracted uronides as determined by the rate of decarboxylation of the uronic units.

## MATERIALS

Geneva muck, Carrington loam (0–3 inches, prairie soil), and Russell silt loam (0–2 inches, forest soil) previously described were used (2).

Cornstalk residues used in these investigations were prepared by composting ground cornstalks in 100-gm. lots in the laboratory with enough nitrogen to bring the total to 1.2 per cent and allowing the material to decompose for 5, 30, and 180 days. Enough water was added to keep the material well moistened but not saturated.

## METHODS

### Extractions

Extractions with sodium carbonate (cold 1 per cent), sodium hydroxide (cold 1 per cent), and ammonium oxalate (hot, 80°C., 0.5 per cent) were made on 30

gm. of soil, 10 gm. of the original ground cornstalks, and 10 gm. of the cornstalk compost samples. The muck and soils were leached with two 100-ml. portions of 1 per cent HCl prior to the alkali and oxalate treatment. Extraction was continued through Pasteur-Chamberland filters of fineness F until no color was observed in the filtrate. The residues were washed free of the reagents with distilled water and dried in an oven at 90°C. The sodium carbonate and sodium hydroxide extractants were neutralized with dilute HCl solution and evaporated almost to dryness on a steam bath prior to determination of uronic carbon.

## Acetylation

Soil (30 gm.) and compost (10 gm.) samples were extracted with ether prior to acetylation. Fifty milliliters of acetyl bromide was added to the samples in 500-ml. reaction flasks, and these were treated at 40–50°C. for 3 days with frequent shaking, according to the method suggested by Springer (6). The residue was filtered in a 150-ml. Büchner funnel with a fine fritted disc, washed thoroughly with ether in a Soxhlet, and dried over $CaCl_2$

### EXPERIMENTAL RESULTS

#### Extraction of uronic constituents

The aforementioned reagents were chosen as extractants primarily because of their performance in solublizing uronides of plant materials. The polyuronide hemicelluloses of some woods have been characterized roughly by their response to extractions with alkali solutions of various concentrations (5, pp. 252–271). Pectin, a polyuronide, is separated from the hemicelluloses by virtue of the former's greater solubility in hot ammonium oxalate solution. All plant uronides are made readily soluble upon acetylation. The solubility of the soil uronides as a result of treatment with these extractants is not known, though Sprigner (6) suggests that acetyl bromide may put both plant and soil uronides into solution.

The extent to which the uronides of muck may be extracted by the various reagents is shown in table 1. Although more than half of the uronic carbon was removed by the sodium carbonate and sodium hydroxide solutions, a proportionate amount of nonuronic carbon was also removed, leaving the ratio of uronic to total carbon similar to that of the original muck. On the other hand, the treatment of muck with ammonium oxalate solution and acetyl bromide solubilized only about one third of the total carbon and about half the uronic carbon. The sum of uronic carbon found in the residues and corresponding extracts often was somewhat lower than that in the original material. This was particularly noticeable when the extracting solution was strongly alkaline. Alkalis are known to have a degrading influence on some plant uronides. This suggestion of degradation was less apparent with soils than with muck (table 2). The data in table 2 also indicate that the uronic carbon of the soils was not preferentially extracted by the alkali solutions, although there was some evidence that ammonium oxalate and acetyl bromide solubilized a slightly greater proportion of uronic than nonuronic carbon.

TABLE 1

*Uronic and total carbon content of Geneva muck as influenced by extraction with sodium carbonate, sodium hydroxide, and ammonium oxalate solutions and by treatment with acetyl bromide*

| TREATMENT | PRODUCT | WEIGHT OF RESIDUE | CARBON IN RESIDUE | CARBON EXTRACTED | URONIC CARBON | Uronic C / Total C |
|---|---|---|---|---|---|---|
| | | gm. | gm. | per cent | gm. | per cent* |
| None | ........ | 10.0 | 4.2 | .. | 0.30 | 7.2 |
| 0.1% Na₂CO₃ | Residue | 8.12 | 3.58 | 15 | 0.27 | 7.5 |
| | Extract | .... | .... | .. | 0.03 | ... |
| 0.5% Na₂CO₃ | Residue | 5.40 | 2.37 | 44 | 0.17 | 7.2 |
| | Extract | .... | .... | .. | 0.09 | ... |
| 1.0% Na₂CO₃ | Residue | 4.86 | 1.74 | 59 | 0.12 | 7.0 |
| | Extract | .... | .... | .. | 0.13 | ... |
| 5.0% Na₂CO₃ | Residue | 5.16 | 1.61 | 62 | 0.11 | 6.7 |
| | Extract | .... | .... | .. | 0.15 | ... |
| 1.0% NaOH | Residue | 3.54 | 1.40 | 67 | 0.10 | 6.9 |
| | Extract | .... | .... | .. | 0.14 | ... |
| 0.5% (NH₄)₂C₂O₄ | Residue | 6.77 | 2.95 | 35 | 0.15 | 5.6 |
| | Extract | .... | .... | .. | 0.12 | ... |
| CH₃COBr | Residue | 7.37 | 2.98 | 29 | 0.16 | 5.4 |

*Note: Chemical formulas above should be read as $Na_2CO_3$, $NaOH$, $(NH_4)_2C_2O_4$, $CH_3COBr$.*

\* Based on carbon in residue.

TABLE 2

*Uronic and total carbon content of Carrington loam and Russell silt loam after extraction with sodium carbonate, sodium hydroxide, and ammonium oxalate and treatment with acetyl bromide*

| TREATMENT | PRODUCT | WEIGHT OF RESIDUE | CARBON IN RESIDUE | CARBON EXTRACTED | URONIC CARBON | Uronic C / Total C |
|---|---|---|---|---|---|---|
| | | gm. | gm. | per cent | gm. | per cent* |
| Carrington loam | | | | | | |
| None | Original | 30.0 | 1.19 | .. | 0.17 | 14.5 |
| 1.0% Na₂CO₃ | Residue | 26.0 | 0.64 | 46 | 0.09 | 14.0 |
| | Extract | .... | .... | .. | 0.05 | .... |
| 1.0% NaOH | Residue | 26.2 | 0.53 | 56 | 0.08 | 15.3 |
| | Extract | .... | .... | .. | 0.06 | .... |
| 0.5% (NH₄)₂C₂O₄ | Residue | 26.3 | 0.80 | 33 | 0.11 | 13.8 |
| | Extract | .... | .... | .. | 0.05 | .... |
| CH₃COBr | Residue | 28.6 | 0.57 | 52 | 0.08 | 13.6 |
| Russell silt loam | | | | | | |
| None | Original | 30.0 | 0.95 | .. | 0.14 | 15.2 |
| 1.0% Na₂CO₃ | Residue | 26.5 | 0.57 | 40 | 0.09 | 15.2 |
| | Extract | .... | .... | .. | 0.05 | .... |
| 1.0% NaOH | Residue | 26.9 | 0.47 | 51 | 0.07 | 15.2 |
| | Extract | .... | .... | .. | 0.06 | .... |
| 0.5% (NH₄)₂C₂O₄ | Residue | 27.3 | 0.62 | 36 | 0.07 | 11.1 |
| | Extract | .... | .... | .. | 0.06 | .... |
| CH₃COBr | Residue | 28.3 | 0.41 | 67 | 0.06 | 15.6 |

\* Based on total carbon in residue.

In order better to understand the transformations that the uronic constituents of plant residues pass through during the process of decomposition before becoming an integral part of the organic matter of soil, cornstalks were composted for various periods and the residues analyzed for uronides after being subjected to the same treatments as the muck and soil. The data in table 3 show that even though the quantity of uronic carbon decreased considerably as decomposition

TABLE 3

*Uronic and total carbon content of cornstalk residues decomposed for various periods and extracted with sodium carbonate, sodium hydroxide, and ammonium oxalate and treated with acetyl bromide*

| TIME DECOMPOSED | TREATMENT | WEIGHT OF RESIDUE | CARBON IN RESIDUE | CARBON EXTRACTED | URONIC CARBON | Uronic Carbon / Total Carbon | |
|---|---|---|---|---|---|---|---|
| *days* | | *gm.** | *gm.** | *gm *| *gm *| *per cent*[†] | *per cent*[‡] |
| 0 | | 100.0 | 48.6 | .... | 2.56 | 5.3 | ... |
| 5 | None | 75.3 | 33.4 | .... | 1.57 | 3.2 | 4.7[§] |
| 30 | | 53.2 | 22.0 | .... | 1.25 | 2.6 | 5.7[§] |
| 180 | | 33.4 | 13.3 | .... | 0.95 | 2.0 | 7.1[§] |
| 0 | | 77.9 | 37.9 | 10.7 | 1.62 | 2.8 | 4.3 |
| 5 | 1.0% Na₂CO₃ | 66.8 | 29.6 | 3.8 | 1.34 | 2.8 | 4.5 |
| 30 | | 40.1 | 16.6 | 5.4 | 0.88 | 1.8 | 5.3 |
| 180 | | 24.9 | 8.3 | 5.0 | 0.66 | 1.4 | 7.9 |
| 0 | | 62.9 | 30.6 | 18.8 | 1.00 | 2.1 | 4.2 |
| 5 | 1.0% NaOH | 54.4 | 24.1 | 9.3 | 1.01 | 2.1 | 4.2 |
| 30 | | 22.8 | 9.4 | 12.6 | 0.48 | 1.0 | 5.1 |
| 180 | | 11.5 | 3.5 | 9.8 | 0.27 | 0.6 | 7.7 |
| 0 | | 79.5 | 38.6 | 10.0 | 1.76 | 3.6 | 4.6 |
| 5 | 0.5% (NH₄)₂C₂O₄ | 66.3 | 29.4 | 4.0 | 1.13 | 2.4 | 3.8 |
| 30 | | 42.8 | 17.7 | 4.3 | 0.80 | 1.7 | 4.6 |
| 180 | | 23.7 | 8.0 | 5.3 | 0.56 | 1.1 | 7.0 |
| 30 | CH₃COBr | 22.2 | 9.2 | 12.8 | 0.41 | 0.8 | 4.3 |
| 180 | | 23.0 | 9.2 | 4.1 | 0.38 | 0.8 | 4.1 |

\* Per 100 gm. original undecomposed cornstalks.
† Of carbon in original cornstalks.
‡ Of carbon in decomposed and extracted residue.
§ Expressed as per cent carbon in decomposed residue.

of the cornstalk progressed, organic residues of increasingly higher uronide content were left. Not all the uronic constituents of cornstalks and cornstalk composts were extractable as a result of the treatment with the alkali and oxalate solutions. Furthermore, only one-third to two-fifths of the uronic carbon of the well-decomposed composts was made soluble by acetylation. There was no indication that treatment of the composts with alkali solutions caused a preferential extraction of uronic constituents from the other organic substances, since the proportion of uronic to total carbon content of the ex-

tracted residues was nearly identical to that of the nonextracted residues.   The oxalate solutions, on the other hand, appeared to extract a slightly greater proportion of uronic than nonuronic carbon from composts decomposed for less than about 180 days, whereas acetylation made a greater proportion of uronic than nonuronic organic constituents soluble at all stages of decomposition.
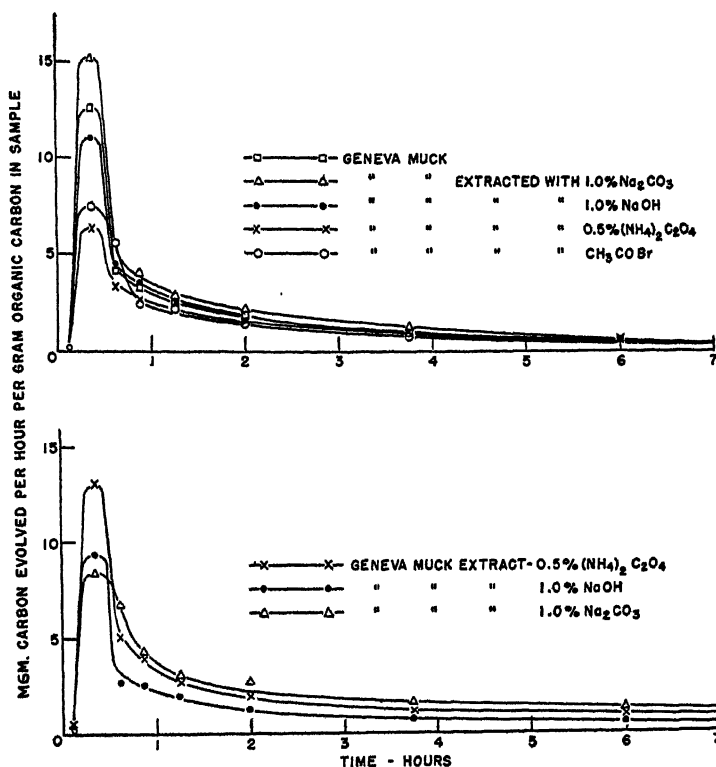


FIG. 1. RATE OF DECARBOXYLATION OF URONIC UNITS OF UNEXTRACTED GENEVA MUCK AND RESIDUES AND EXTRACTS OF THE MUCK

*Decarboxylation rate of uronic units of extracts and residues of muck, soils, and composts*

No evidence was furnished by the quantitative data to indicate that the extracted uronic constituents of muck, soils, and composts were any different from those that remained in the residues.   However, that the uronic and nonuronic carbon was extracted in nearly equal proportions could be interpreted to mean that some factor other than the solubility of the uronide-containing constituents alone was involved in the extraction.   In an attempt to learn more surely whether or not qualitative differences between the uronic constituents of the extracts and residues exist, the rate of decarboxylation of the uronic units from both sources was determined.
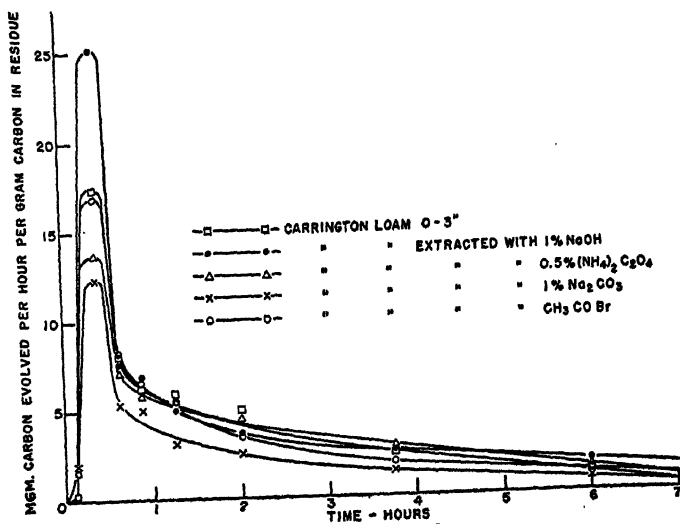
FIG. 2. RATE OF CARBON EVOLUTION FROM URONIC UNITS OF ORIGINAL AND EXTRACTED
CARRINGTON LOAM (0–3 INCHES)
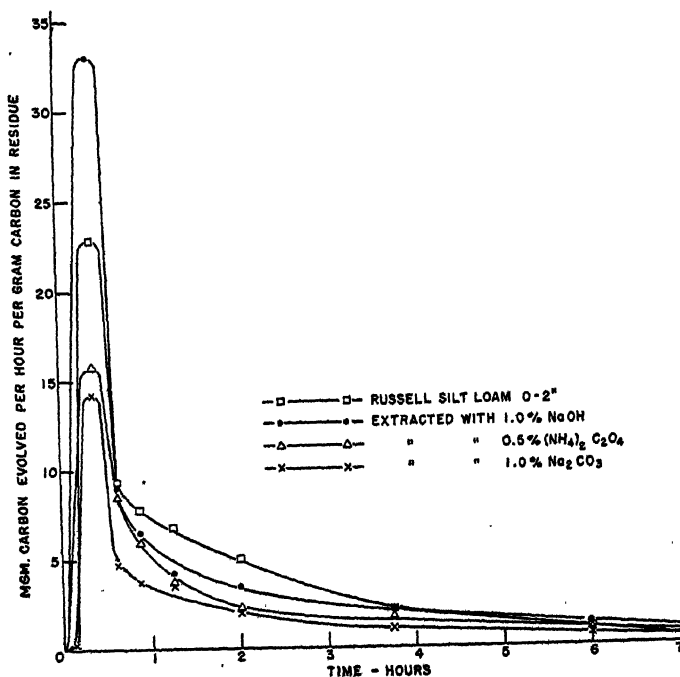


FIG. 3. RATE OF CARBON EVOLUTION FROM URONIC UNITS OF ORIGINAL AND EXTRACTED
RUSSELL SILT LOAM

Figure 1 shows that although the rate of decarboxylation of the muck residues and extracts closely resembled that of the original material, the rate at which the first increment of carbon dioxide was evolved differed slightly with the different

TABLE 4

*Rate of decarboxylation of uronic units of cornstalks and extracted cornstalk residues as influenced by microbial decomposition*

| DECOMPOSED | Preheating 0.25 hr. | Boiling Time | | | | | | | CARBON EVOLVED |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.5 0 hr. | 0.75 hr. | 1.00 hr. | 1.50 hrs. | 2.50 hrs. | 5.00 hrs. | 7.00 hrs. | |
| days | mgm.* | mgm.* | mgm.* | mgm.* | mgm.* | mgm.* | mgm.* | mgm.* | mgm. |
| *Not extracted* | | | | | | | | | |
| 0 | 0.1 | 5.3 | 3.9 | 3.5 | 2.4 | 1.6 | 0.8 | 0.4 | 4.3 |
| 5 | 0.2 | 5.5 | 2.8 | 2.7 | 1.9 | 1.3 | 0.7 | 0.4 | 3.4 |
| 30 | 0.3 | 8.4 | 4.0 | 2.8 | 2.1 | 1.5 | 0.8 | 0.5 | 3.9 |
| 180 | 0.3 | 8.9 | 4.1 | 3.6 | 2.7 | 1.4 | 1.1 | 0.7 | 4.7 |
| *Extracted with 1.0% $Na_2CO_3$* | | | | | | | | | |
| 0 | 0.2 | 4.1 | 3.1 | 2.3 | 1.8 | 1.5 | 0.6 | 0.4 | 3.5 |
| 5 | 0.3 | 5.0 | 3.4 | 2.7 | 2.0 | 1.3 | 0.6 | 0.4 | 3.4 |
| 30 | 0.3 | 6.3 | 4.1 | 3.2 | 2.3 | 1.5 | 0.7 | 0.5 | 3.7 |
| 180 | 0.5 | 11.9 | 5.1 | 4.4 | 2.9 | 2.1 | 1.1 | 0.7 | 4.5 |
| *Extracted with 1.0% NaOH* | | | | | | | | | |
| 0 | 0.2 | 3.4 | 1.6 | 1.4 | 1.3 | 1.2 | 0.5 | 0.3 | 2.6 |
| 5 | 0.6 | 7.7 | 2.8 | 2.0 | 1.7 | 0.9 | 0.5 | 0.4 | 3.1 |
| 30 | 0.5 | 8.3 | 3.1 | 2.4 | 2.3 | 1.4 | 0.7 | 0.5 | 3.5 |
| 180 | 0.8 | 11.4 | 5.3 | 4.8 | 3.4 | 2.6 | 1.2 | 0.8 | 4.3 |
| *Extracted with 0.5% $(NH_4)_2C_2O_4$* | | | | | | | | | |
| 0 | 0.1 | 3.5 | 3.1 | 2.7 | 1.8 | 1.1 | 0.5 | 0.2 | 3.7 |
| 5 | 0.3 | 3.0 | 2.9 | 2.3 | 1.7 | 1.3 | 0.6 | 0.4 | 2.8 |
| 30 | 0.4 | 4.9 | 2.9 | 2.5 | 1.9 | 1.5 | 0.7 | 0.4 | 3.1 |
| 180 | 0.3 | 7.1 | 4.3 | 3.8 | 2.4 | 2.0 | 1.2 | 0.7 | 3.9 |
| *Acetylated and extracted with $CH_3COBr$* | | | | | | | | | |
| 30 | 0.4 | 6.1 | 3.3 | 2.2 | 1.6 | 1.1 | 0.6 | 0.4 | 3.1 |
| 180 | 0.4 | 6.5 | 3.3 | 2.2 | 1.9 | 1.4 | 0.7 | 0.5 | 2.8 |

* Per gram carbon in residue.
† Per gram residue.

samples. Except for muck extracted with sodium carbonate, the initial rate of decarboxylation of the uronic units of the residues was less than that of the unextracted material. The relationship between the rates of decarboxylation of the uronic units of original and extracted samples of Carrington loam and Russell silt loam as shown in figures 2 and 3, respectively, was similar to that of the muck

samples.   The decarboxylation rate of the uronic units of the soils treated with acetyl bromide was nearly identical to that of the original soil.

A comparison between the decarboxylation rate of uronic units of extracted and unextracted cornstalks and cornstalk composts is shown in table 4.   The extracted residues of cornstalks in similar state of decomposition decarboxylated at a rate like that of the unextracted residues except during the initial $\frac{1}{4}$-hour boiling period, at which time residues extracted with sodium carbonate, ammonium oxalate, and acetyl bromide had a lower rate of decarboxylation and those extracted with sodium hydroxide a higher rate.   In all instances, the uronic units of the extracted undecomposed cornstalks evolved carbon dioxide at a less rapid rate throughout the determination than did those of unextracted cornstalks.   This difference became less apparent as decomposition progressed, being of no consequence after the material had lost half of its weight as a result of composting (about 30 days).

<div align="center">DISCUSSION</div>

Organic matter may be extracted from soils by numerous chemical solutions. Indeed, the susceptibility of organic matter to extraction by alkali solutions, peptization by inorganic salts, and acetylation with acetyl bromide has been suggested as being useful in its characterization.   These methods of separation are wholly empirical and their effectiveness varies considerably with concentration of the reagent, temperature, and time of the reaction.   Taken by themselves, they are of doubtful value for characterization purposes.   Little information as to the composition of the partitioned components has been offered except that the carbon:nitrogen ratio of the residues and extracts are about the same.

The ratios of the uronic to total carbon of extracts and residues of soils and composts reported here were also much alike.   Furthermore, the decarboxylation rate of the uronic units of extracts and residues resembled that of the unextracted samples.   Thus it appears that organic matter from a single soil type may be looked upon as being so constituted as to be rather homogeneous, and existing methods designed to partition organic matter result only in the liberation of a homogeneous material quite like that retained.   The fact that uronic and nonuronic organic constituents in soils are extracted in about equal proportions by the various treatments also indicates that these constituents may be combined. The nature of this combination is not clear.   Combination of uronic constituents with other parts of the soil organic matter could take place either through hydroxyl or carboxyl groups and in the latter case could involve either ester or salt formation.   Such combination, if present, need not involve more than a small fraction of the hexose units in the polyuronide.   Mere mechanical or adsorptive association of uronic acids with other organic material does not change the rate of $CO_2$ evolution with boiling 20 per cent HCl (2) and would not be expected to influence solubility in alkali.   The suggestion of a combination of the uronides and other organic soil constituents is significant, inasmuch as it affords an explanation for the resistance of the soil uronides to rapid microbial attack and implies that the uronides need not depend upon the association or

combination with inorganic groupings for this resistance. However, the possibility that uronic constituents of soils owe their relative stability to a type of architecture peculiar to microbial polyuronides, from which they are thought to originate, rather than to their union with either organic or inorganic groupings must still be considered. Unfortunately, nothing is known about the intimate structure of the uronic constituents in soil.

As more is learned about their characteristics, it becomes increasingly evident that the soil uronic constituents are distinctly different from those of plants and are not likely to originate directly from plants. Uronic constituents of plants and soil organic matter differ not only in the rate at which their uronic units decarboxylate (1) but also in their reaction to alkali and acetyl bromide treatment. By treatment with alkali solution and acetylation with acetyl bromide, polyuronides of plants may be made more completely soluble than the uronides of soils. Moreover, the uronic units that are extractable from soils decarboxylate at a rate very similar to that of units retained in the soil and units of the original soil, rather than like the units of plant materials and extracted plant constituents such as pectin and polyuronide hemicelluloses.

## SUMMARY

The solubility of the uronides of a muck, two soils, and cornstalk composts in 1 per cent cold sodium carbonate and sodium hydroxide and 0.5 per cent hot ammonium oxalate and acetyl bromide is given. The quantity of uronic carbon extracted by the cold alkali treatment was about proportionate to the amount of nonuronic carbon extracted, being roughly one-third to one-half of that originally present. There was some evidence that the hot ammonium oxalate and acetylation treatment solublized a slightly greater proportion of uronic than nonuronic carbon of soils. The uronic constituents of the extracted residues of muck, soils, and composts decarboxylated at a rate little different from that of the uronic constituents of the oritinal materials or the extracts.

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# AZOTOBACTER INOCULATION OF CROPS: I. HISTORICAL

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The recent interest that has been created by the rather extensive use in the USSR of "Azotogen" as a seed inoculant makes it desirable to assemble the available scientific knowledge of the value of such inoculations with free-living bacteria for the purpose of increasing crop yields. It is reliably reported (4) that "Azotogen," which is a commercial preparation of *Azotobacter chroococcum* in a peat–soil–calcium-carbonate mixture, was used on 5 million acres of crops in the USSR in 1942. The use of this material was initiated about 1932, and since that time active research on bacterial inoculants has been conducted by a number of Soviet scientists. As will be evident from the present review, these investigations represent a revival of interest in an old subject that at one time engaged the attention of a considerable number of soil bacteriologists. In the present review particular attention will be given to the more recent results. A few papers are not mentioned since neither the original nor an adequate abstract was available.

## STUDIES WITH AZOTOBACTER AND OTHER NONSYMBIOTIC BACTERIA

### *Investigations reported during 1895–1928*

Interest in the possibility of bringing about nitrogen fixation and increased crop yields through inoculation of soils and plants with free-living bacteria dates back almost to the beginning of the science of soil bacteria (109). The first published claim of such benefits was probably that of Caron (16) in 1895. He (16, 17) obtained marked increases in the yields of nonlegumes by inoculation with cultures of various organisms isolated from soils and composts. A preparation of *Bacillus ellenbachensis* was sold commercially under the name of "Alinit." Stoklasa's (95) work checked that of Caron, but several other bacteriologists (109) obtained negative results. Evidently Caron's views remained unchanged, for in subsequent articles (18, 19, 20) he presented additional data to show that barley can utilize nitrogen if inoculated with the proper organisms.

Following the discovery in 1901 of the nitrogen-fixing organism, Azotobacter, several new inoculation studies were started. In pot experiments, using *A. chroococcum*, Gerlach and Vogel (32) obtained increased yields of 10 per cent with oats, 42 per cent with mustard, and a decrease of 20 per cent with carrots. Negative results were obtained with beets grown in the field. In cylinder experi-

ments Lipman and Brown (65) obtained no benefits from the addition of two species of Azotobactr to fallow soils followed by a rotation. Straňák (99) and Stoklasa (96, 97, 98) reported marked increases in yields of beets, oats, and potatoes following inoculation of the soil with Azotobacter. Stoklasa found that adequate sugar and lime were essential.

Bottomley published a series of about fifteen papers (10, 11, 12, 13) during the period of 1907–1920 dealing with bacterized peat, called "humogen." Added to this material in the course of preparation were A. chroococcum and Rhizobium. Bottomley's experiments indicated that the marked growth-stimulating action of the material might be due to the presence of substances similar in nature to animal vitamins. We now know, however, that minor elements were responsible for much of the benefit that Bottomley obtained. Russell (79) failed to confirm Bottomley's findings.

As a result of greenhouse experiments, using Azotobacter for inoculation, Emerson (26) concluded that bacterial inoculation is profitable if the soil environment is favorable and if adequate nitrogen-deficient organic matter is present. In tests of an "all-crops" inoculum, he (27) observed no consistently favorable results. Likewise, Nolte (73) obtained no benefits with oats and mustard from the use of three so-called nitrogen bacterial fertilizers. Zucker (117) also reported negative results from the use of a mixed culture of Azotobacter. Experiments of Düggeli (25), however, indicated that free-living nitrogen-fixing bacteria were able to supply nitrogen to crops.

When field soils were inoculated with Azotobacter, Makrinoff (68) obtained increased yields of both legumes and nonlegumes ranging from 0 to 156 per cent; where cellulose-decomposing bacteria were also supplied together with Azotobacter the effects were usually even greater. In eight tests with Azotobacter alone, six were positive. When both organisms were supplied, eight out of nine tests were positive.

In inoculation experiments, using three strains of Azotobacter, Brown and Hart (14) obtained some increases in the total nitrogen supply in Carrington loam cropped to wheat, but the crop yields were not increased. Gainey (31) believed that failures in inoculation with Azotobacter may frequently be due to the acidity of the soil, since pH 6 is the limit tolerated by this organism.

During the period of 1925 to 1927 Truffaut and Bezssonoff (103, 104, 105) reported experiments from which they concluded that corn can grow to maturity in a medium to which no nitrogen has been added if the proper nitrogen-fixing bacteria are supplied. They claimed that Clostridium Pastorianum and Bacillus Truffauti live in close association using root secretions as a food.

In this connection it is pertinent to mention the observation of Löhnis (67), and many others, that leguminous crops often exert a marked beneficial effect upon succeeding crops apart from the nitrogen they supply. Löhnis observed that one of the main reasons for this is the stimulation of bacterial activities resulting from the growing crop. The increase might be greater than that resulting from inoculation.

## Investigations in the USSR reported since 1928

Research on nonsymbiotic bacterial inoculants was undertaken with renewed interest by a number of Soviet investigators beginning about 1928. From the first, many of these workers seem not to have doubted that soil inoculation with Azotobacter is a practical procedure.

Sheloumova was one of the first of the more modern school of workers on bacterial inoculation in Russia. In her (85) first experiments, yields of tobacco, mustard, and corn were increased an average of about 24 per cent by inoculation of unlimed soil with Azotobacter; the increase was 16 per cent in the presence of lime. The corresponding increases in the introgen content of the crops were 26 and 1 per cent, respectively. Since these results were obtained on soils that contained adequate nitrogen and were capable of active anaerobic nitrogen fixation, she suggested that the effect of Azotobacter may be only subsidiary. In later experiments Sheloumova and co-workers (87) attempted to determine the long-time effect of inoculation, but the results of successive croppings were erratic. In other similar experiments, conducted by Sheloumova and Protodiakonov (86), inoculation produced a 5 per cent beneficial effect on tobacco and 18 per cent on corn.

In small field experiments, conducted at various places in the USSR by Sheloumova and co-workers (89), Azotobacter increased the yields of beets, potatoes, and corn from 10 to 82 per cent. Other field experiments (90) gave an average increase of 29 per cent for potatoes and barley in one year, and 37 per cent for barley the following year.

In her discussion of the nature of Azotogen action, Sheloumova (91) reported that the effect is due to the nitrogen-fixing action of Azotobacter. Filtrates or sterilized cultures of Azotobacter, according to her, are ineffective as plant-growth stimulants; seasoned peat is also ineffective unless it acts as a carrier of the bacteria. The addition of cultures of Bacterium fluorescens and Bacillus mycoides, either singly or in combination with Azotogen (90), gave essentially no effect on the yields of oats or barley. She (88) considered that Azotobacter uses the root secretions as a source of energy for growth and nitrogen fixation. In some instances, as in the case of corn, the plant itself may stop fixation by acidifying the medium to below pH 6.

Extensive field experiments by Savostin and co-workers (80, 81, 82) gave increased yields of wheat and oats, due to Azotobacter additions, that varied from 0 to 54 per cent, with an average increase of near 25 per cent. Savostin listed the important factors as adequate lime, available energy, suitable temperature, good aeration, and adequate minerals. The addition of cellulose bacteria together with Azotobacter, sometimes proved beneficial, particularly if peat was present to serve as an energy source. The ideas of Savostin and co-workers as to the mechanism by which Azotobacter increases crop yields agree closely with those of Sheloumova: nitrogen is fixed by Azotobacter, converted into amines by the bacteria, and then assimilated by the higher plant.

In a greenhouse experiment, using a rich soil, Demidenko and Timofeieva (23)

obtained an average increase of 43 per cent in yield and of 130 per cent in nitrogen content of sugar beets due to Azotobacter. Field experiments, however, gave a negligible increase. In other experiments (24) inoculation increased the dry weight of oats by 13 per cent. Where oats and peas were grown together in the presence of nodule bacteria the addition of Azotobacter increased the total dry weights of oats 30 per cent and of peas 28 per cent. In the opinion of these workers the increases are due to the nitrogen fixed by Azotobacter living on root secretions.

Federov (28) showed that the introduction of Azotobacter, together with straw, gave marked increases in yields for the second and third years but not for the first. He (29) stressed the necessity for an abundant available energy source of wide carbon-nitrogen ratio.

Meshkov (70) reported that the average yearly increase in the yield of maize during a 5-year period, due to nitrogen fixation by Azotobacter using root excretions as an energy source, was 20 per cent where partly sterilized soil was used as a culture medium; in nonsterilized soil the effect of inoculation was negligible. The frequent addition of small quantities of glucose or benzoic acid, together with Azotobacter, sometimes depressed the yields the first year but had a favorable effect in later years.

In pot experiments, increases of 11 to 13 per cent in the yields of wheat, due to additions of Azotobacter, were reported by Henckel (35). There was no significant difference in yields where the seed alone were inoculated and where the organisms were mixed with all of the soil.

In work done more recently than that already mentioned, Makrinoff (69) reported good results from the use of heavy applications of "bionitrified" peat to soil, and attributed its effect to the high content of Azotobacter and nitrifying organisms.

Federov and Tepper (30) pointed out that when poor results are obtained from Azotobacter inoculations the failure is commonly due either to insufficient excretion of carbonaceous materials from the roots or to unfavorable conditions for growth of Azotobacter in the rhizosphere. In their own experiments with millet they observed a sharp drop in the number of Azotobacter following inoculation, with few or none of those organisms present at the time of blossoming. Sometimes they increased later. The determining factor was not the soil but the activity of the plant root system and the rhizosphere bacteria. In laboratory experiments these rhizosphere bacteria, or their filtrates, depressed the growth of Azotobacter but the latter stimulated the former. These two workers suggested that the solution may lie both in the selection of strains of Azotobacter that can compete with rhizosphere bacteria and in the improvement of plant-growth conditions. Additions of straw are often beneficial.

A very interesting set of greenhouse experiments was reported by Oknina (75), who treated oats and barley seeds with Rhizobium from the pea plant and with Azotobacter. The experiment is unique in that she used a nitrogen-free quartz sand to which a nutrient solution, including ammonium nitrate at two levels, was added. At the higher nitrogen level the increases in total dry weights of the

barley amounted to 21 and 31 per cent for the Azotobacter and Rhizobium treatments, respectively. The corresponding values for oats were 27 and 18 per cent. At the lower level of ammonium nitrate slightly negative values were obtained with barley, and 10 to 15 per cent positive results with oats, for the two bacterial treatments. The total nitrogen values were variable but fairly closely correlated with the yields. The fact that the greatest effects of inoculation were obtained in the presence of the higher concentration of ammonium nitrate indicates very strongly that the results were not due to nitrogen fixation. Azotobacter fixes little or no nitrogen in the presence of ammonia (38) and rhizobia never (1) fix it apart from the host. The results might be interpreted to indicate the production of small quantities of biological activators by the bacteria that lived on the root excretions.

Another leading Soviet investigator on rhizosphere bacteria during this period was Isakova. Her first works (39, 41) showed that seed germination may be markedly favored by treatment with various suspensions of bacteriorhizal complexes. The effect was presumably due to cell metabolic products, since cell-free filtrates usually gave better results than the unfiltered preparations. Boiling sometimes lowered and sometimes increased the effect. The bacteriorhiza population of a given plant is very specific, according to Isakova and Smirnova (40), and there is no uniformity in the way various microbe complexes affect the development of the plant. In other work, Isakova (44) found that addition of all the necessary mineral nutrients decreased the effect of added bacteria on peas, wheat, and an oat-vetch mixture. Additional experiments (42) supported her thesis of plant stimulation through the production by bacteria of substances of the hormone type.

In her initial studies (43) with Azotobacter, Isakova seems to have accepted as an established fact that inoculation with this organism is beneficial to higher plants. She evidently accepted the hormone hypothesis, rather than the nitrogen-fixation idea, and proceeded to test it. Experiments were conducted in pots using a rich hotbed humus without the addition of nutrients. Inoculation was accomplished by soaking the seed for 24 hours, followed by subsequent inoculations in some cases 32 and 49 days later. The results show a striking effect of inoculation, but the effect of Azotobacter on sugar beets was not much greater than that of the bacterial complex from the root systems of various plants. The combination of Azotobacter and the rhizosphere organisms usually gave the largest yields. Similar experiments (45) with wheat gave much less striking results and several negative values.

Azotobacter isolated by Isakova (46) from the roots of various plants showed only weak nitrogen-fixing powers. She considered this due to the adaptation to a synergetic life. More likely, failure to fix nitrogen was due to inadequate iron and molybdenum in the Ashby's medium used.

According to Isakova (47), when seeds are inoculated with Azotobacter, or other suitable soil organisms, the products of metabolism penetrate into the seed and affect the biochemical and fermentative processes. Azotobacter from flax increased (48) the vitamin C content of wheat from 0.91 to 3.96 mgm. Those

from peas, hemp, and oats gave smaller, but marked, increases, Vitamin $B_1$ production was sometimes increased but often decreased. Isakova also reported (47) that both Azotobacter and tyrosine-decomposing bacteria caused marked changes in seed germination, followed by an effect on plant development, catalase activity, and nitrogen content. Not all results were positive. She emphasized the role of auxins and the inadequacy of the nitrogen-fixation ideas of Sheloumova and others. The phenomenon is, however, of a complicated order, and until all of the factors are better understood she considers it not surprising that inoculation with Azotogen does not always give positive results.

The results of Berezova, Naumova, and Rasnizina (5) are in close agreement with those of Isakova. They showed that both *A. chroococcum* and *Pseudomonas fluorescens* are intensive producers of growth substances of the auxin type. Flax seedlings, when treated with suspensions of *A. chroococcum*, were stimulated prior to the time that an external source of nitrogen was required and were also less subject to attack by diseases; the results with wheat were less striking. Seed treatments of wheat with *A. chroococcum* and *P. fluorescens* gave increased grain yields of 24 and 17 per cent, respectively, even though the soil had received a complete fertilizer. The corresponding increases in the yields of flax seed were 20 and 10 per cent.

Krassilnikov (60, 61) emphasized that the root system tends to control the organisms that grow near it. Added organisms, such as Azotobacter or Pseudomonas (59, 64), may or may not affect the population. Beneficial effects are due to an active factor excreted by the microorganisms and which may be isolated by filtration or alcohol extraction. Filtration through Berkefeld filters decreased the activity, and heating to 100°C. partly destroyed it. Krassilnikov (59) considered that a substance of the hormone type, rather than of the bios group, was indicated. Studies with legumes (62) gave similar results.

Several Soviet scientists (6, 7, 8, 71, 74) have given attention to the antagonistic effects of bacteria on pathogenic soil fungi. Novogrudskij and co-workers (74) asserted that some of these bacteria suppress the development of fungi, whereas others lyse the mycelium. When flax seed were "bacterized" for 24 hours with various organisms, marked effects were sometimes observed. The beneficial effect of the bacterial growth products were destroyed by heating for 10 minutes at 100°C. but not at 80°C. Berezova (6) and Berezova and Naumova (7) found, in general, that bacterization decreased infection and increased yields of flax. According to Berezova and Naumova, these "mycolytic" bacteria are more abundant around the root systems of leguminous than of nonleguminous plants and are especially abundant at the flowering stage. The best inoculation results were obtained with a mixture of *A. chroococcum* and an organism designated as *strain F 24*. In another publication Naumova (71) reports similar beneficial results with wheat using three strains of mycolytic bacteria. In addition, seedlings were also stimulated by *A. vinelandii*, *A. chroococcum*, *P. fluorescens*, and *B. ellenbachensis*. Berezova (8) sometimes observed harmful effects from the addition of *Bacillus amylobacter* to flax if the inoculation was too heavy. Best results were obtained where all the nutrients were present in

adequate quantities. In studies with spring wheat, Khudyakov and Rasnizina (55) observed that the addition of mycolytic bacteria, or the filtrates from the cultures, to seeds during vernalization prevented infection by fungi and increased the grain yields.

Among the comparatively few workers in the USSR who have failed to obtain positive results from inoculations with Azotobacter is Turchin, whose recent work (106) deserves particular attention. He tested two Azotogen preparations in pot cultures and in the field under conditions of adequate minerals other than nitrogen. The following soils and crops were used:

| TYPE OF EXPERI-MENT | SOIL | CROPS |
|---|---|---|
| Field | Limed, podzolic loam | Oats, mangels, flax |
| Pot | Limed, podzolic loam | Barey, corn, potatoes, beets |
| Pot | Limed, podzolic sandy loam | Oats |
| Pot | Carbonitic gray soil | Barley |
| Pot | Podzolic loam plus peat | Corn |
| Pot | Sand | Corn |

*Investigations, other than those in the USSR, reported since 1928*

A number of Indian workers have reported experiments, or made observations, that lead them to believe that rice, corn, and other plants obtain nitrogen from the air by means of bacteria, especially Azotobacter, that live in the soil and rhizosphere.

Vyas (110) reported that roots secrete products of unknown nature that stimulate the activities of nitrogen-fixing bacteria.

Bahadur and Sahasrabuddhe (3) pointed out that cropped rice soils tend to be higher in total nitrogen than uncropped soils. The rate of nitrogen fixation was reported to be particularly high in the rhizosphere.

The inoculation experiments of Karunakar and Rajagopalan (52) gave especially striking results. In their greenhouse experiment, replicated five times, a sterilized soil of medium fertility was used. The sorghum seed were soaked for an hour in a culture of Azotobacter just prior to planting. Yield increases due to inoculation varied from 28 to 34 per cent for the grain and from 36 to 74 per cent for the straw. Experiments conducted in lysimeters with unsterilized soil gave similar increases in grain yields but somewhat smaller effects on straw yields. In field tests, replicated five times, inoculation increased the yield of sorghum grain 22.7 per cent and straw 10.6 per cent. All of these experiments were planned for statistical treatment, and the results are highly significant. The authors suggest that the effects may be due to a "bioeffect" on the plant, or inoculation may locate the organisms at the spot where they are most needed for supplying nitrogen to the seedling.

Uppal, Patel, and Daji (107) stress the importance of Azotobacter in maintaining the nitrogen supply in rice soils. They believe that the plant stimulates the bacteria to greater activity and efficiency of nitrogen fixation, partly by increasing the pH of the medium.

In recent years only a few workers outside the USSR and India have given serious consideration to the use of nonsymbiotic nitrogen-fixing bacteria for soil. inoculation. Jensen (49), however, made an exhaustive study of the occurrence and probable value of Azotobacter in Australian wheat fields. Only about a third of the soils contained this organism and then only in small numbers. It was not found in the rhizosphere of wheat plants taken from soils otherwise free from Azotobacter. Even in an alkaline soil the number of this organism in the rhizosphere was not high, and Jensen concluded that the bacteria were of little practical importance. In other studies (51) inoculation of alfalfa and white clover with *A. chroococcum*, in addition to Rhizobium, produced no significant effect. Intact roots did not appear to excrete organic substances that favored Azotobacter.

Although Schanderl (83, 84) did not make Azotobacter inoculation studies, his work is of interest because of his conclusions that many nonleguminous plants can fix atmospheric nitrogen as a result of living in symbiosis with bacteria.

In long-time greenhouse experiments with soils, Greaves and Jones (34) reported an annual gain of nitrogen per acre-foot of soil of 27 to 38 pounds. These soils were initially inoculated with *A. chroococcum*, but there is no certainty that the gains were due to this organism.

Even when adequate lime and energy materials were supplied to soils, Katznelson (53) found that Azotobacter would not always thrive. This may be due to inability to compete with other soil organisms, to toxic substances, or to deficiencies. Poschenrieder (76, 77) discussed this subject at an earlier date. The failure of Azotobacter to live in soils is sometimes due to lack of molybdenum, as Van Niel (108) has shown. The various species and strains of this organism show (37) marked variations in their response to this element. Even if abundant in soils, Azotobacter may not be living entirely on free nitrogen gas, since any appreciable quantity of ammonia (38) may be used preferentially.

### SOME CLOSELY RELATED RESEARCHES OF ESPECIAL INTEREST

Other studies of interest in this discussion include various miscellaneous papers showing the effect of higher plants on soil microorganisms and some of the work dealing with the response of the plant to organic growth substances.

### *Influence of higher plants upon soil microorganisms.*

The extensive work of Starkey (93) gives a good picture of conditions in the rhizosphere. He found that higher plants vary in their effect upon the soil organisms, but in general the effect is marked on the population as a whole, and especially on the *Bacterium radiobacter* group of organisms. The most marked increase in bacteria occurred subsequent to the seedling stage and was more marked for biennials and plants having a long growing season. The root surface, especially of legumes, was found to be highly populated. The physiology of the plant, particularly the quantity and quality of the root secretions, seemed to be the factor that determined the root population in any given case.

Clark (21) observed large numbers of bacteria near or on the surface of roots. Pseudomonas and Phytomonas fluorescent types were especially abundant. Azotobacter was not found in large numbers on the root surfaces of plants grown in soils that were generally free from this organism.

Numerous other investigators (33, 57, 58, 63, 66, 94, 100, 101, 116) have reported work that agrees in showing an abundant bacterial population in the rhizosphere. Thom and Humfeld (100) showed that the root surface tends to be maintained at a pH near the optimum for bacteria regardless of the pH of the soil. Krassilnikov, Kriss and Litvinov (57, 58) attributed the large numbers of bacteria in the root zone of various plants both to the physical effects of roots and to the organic excretions. The total numbers of organisms present reached the highest values during the early period of rapid vegetative growth and again later during fruiting. These numbers in the rhizosphere varied (63) from 10 to 50 millions per gram, depending upon the fertility of the soil. Adjoining soils had only one third, or even less, this number of organisms.

Lochhead (66) found that not only were bacteria more abundant in the rhizosphere but they were much more active physiologically. West and Lochhead (116) observed that bacteria near the roots of flax and tobacco possessed more complex nutritive requirements than those in the control, thus suggesting that the roots may excrete such substances as biotin, thiamin, and amino nitrogen.

Sidorenko (92) reported that the root systems of barley, oats, Sudan grass, and sunflowers were favorable to the development of Azotobacter; soybeans were slightly less so; and wheat was depressing. The stage of development of the plant was also important. The selective action of plant roots on soil organisms in both manured and unmanured soil is stressed by Katznelson's (54) work with mangels. The effect was greatest near maturity. No rhizosphere effect was noted with Azotobacter.

### Response of higher plants to organic growth substances

Though certain organic substances, such as vitamins, auxins, and hormones, are known to hasten the formation of roots or sometimes stimulate the growth of seedlings, there is little tangible information to show that such materials increase the final crop yields. A few articles of interest in this connection are mentioned here because such materials are known to be produced by Azotobacter and other soil organisms.

In work with isolated pea embryos, Kögl and Haagen-Smit (56) obtained marked increases in growth following additions of yeast extract to the medium. The combination of biotin, thiamin, and oestron increased the dry weight of shoots 53 per cent and of roots 21 per cent.

When wheat seeds were soaked in either urine or yeast extract there was usually a marked increase in the growth of the young plants and in the final yield, according to the work of Tovarnitskij and Rivkind (102). Yield increases of 25 to 50 per cent were not uncommon. Vetch showed no response. Beets gave a 21 per cent increase with yeast water and a 52 per cent response to

urine. The authors attributed the increases to auxins, bios, and other substances of the B group. In contrast, Decoux and Vanderwaeren (22) obtained little or no effect from soaking sugar beet seed in solutions of nicotinic acid, α-naphtylacetic acid, indoleacetic acid, and urine.

Brown (15) concluded that there is abundant evidence that in some cases seeds, pollen grains, and fungus spores will not germinate in the absence of external supplies of biological activators. Sometimes (72) the germination of old seeds is also made possible by such activators, or possibly antibiotics.

The ability of bacteria to synthesize various kinds of growth substances is so well established that it is unnecessary to review the literature in detail. Some organisms synthesize many types of such substances, whereas other organisms must be supplied with them. Marked differences occur even between species within a genus. For instance, biotin synthesis by species of Rhizobium may vary (2) from none to abundant. Azotobacter actively synthesizes this vitamin. With the possible exception of yeast, Azotobacter is about the most active synthesizer of growth substances known, as regards type and quantity of substances. According to Rasnizina (78) *A. chroococcum* and some strains of *P. fluorescens* are the most intensive producers of growth substances of the auxin type among the rhizosphere bacteria. *A. agile* produces smaller quantities and *A. vinelandii* little or none.

The extensive literature on the role of vitamins, hormones, and auxins in plant development has been summarized by Bonner (9) and by Went (114, 115). Most of the pertinent information on antibiotic effects of organisms, still rather meager with respect to plant growth, is summarized by Waksman and Woodruff (111), Waksman (112, 113) and by Höogerheide (36).

### DISCUSSION OF SUGGESTED EXPLANATIONS FOR BENEFICIAL EFFECTS OF INOCULATION REPORTED BY SEVERAL WORKERS

The foregoing review has emphasized the lack of agreement as to the value of inoculating higher plants with Azotobacter. Even those who have obtained positive results do not agree as to the reasons for the benefits. A critical consideration of the suggested explanations follows.

### *Nitrogen fixation in the rhizosphere*

One of the most common explanations given for the beneficial effects of inoculation is that the added Azotobacter fix atmospheric nitrogen, which is later made available for use of the higher plants. The energy source for bacterial growth may come either from root excretions or from decomposing plant materials. On the basis of our present knowledge, this explanation can be discarded, or at least minimized to the point of nonimportance. This positive statement is based upon several facts: (*a*) No one has demonstrated that Azotobacter thrives in the rhizosphere or is present in sufficient numbers, following inoculation, to bring about any appreciable fixation. (*b*) There is little or no evidence that root excretions are of sufficient magnitude to provide energy for more than traces of nitrogen fixation. (*c*) Where crop residues are present, most of the energy sources are not available to Azotobacter and are made available only as

a result of attack by other organisms, which use most of the energy themselves. Even with sugar as the energy source, and in the absence of competitive organisms, Azotobacter seldom fixes more than 1 pound of nitrogen per 100 pounds of this carbohydrate. (d) According to several workers in the USSR, various species of bacteria that do not fix nitrogen, or even their filtrates, produce beneficial effects similar to those attributed to Azotobacter. (e) A few workers have also reported that yield increases were obtained even in the presence of abundant available nitrogen.

### Protection of the higher plant against pathogenic organisms

Several Soviet workers have stressed the value of Azotobacter and other organisms, or their filtrates, in preventing seed and plant infections by fungi. Our knowledge of antibiotic effects, and of biological antagonism, in general in the soil, is too limited at present to evaluate possible effects on crop yields. It seems highly improbable, however, that the beneficial effects of Azotobacter, observed in the USSR, can be attributed to such causes. Benefits from Azotogen have been reported under conditions where there was no indication that disease was an appreciable factor. Furthermore, Azotobacter is an organism that is unlikely to attack or inhibit other organisms, especially fungi. It is more likely that the fungi would inhibit Azotobacter, since fungi can live on cellulose and other plant materials that are unavailable to Azotobacter. Evidence is also lacking as to the ability of this organism to produce antibiotic substances or to attack fungi directly.

### Production of plant-growth accelerators

The most plausible explanation for the beneficial effect of Azotogen on plant growth, if there is such an effect, would seem to be that the bacteria produce substances, especially auxins and hormones, that speed up the rate of plant growth. As already pointed out, only rarely have such effects been reported when pure preparations of such materials have been tested, and, even then, only under abnormal conditions. It is well to bear in mind, though, that if an outside supply of these substances is needed, only traces are required. Since these substances are readily destroyed in the soil, it is possible that a continuous bacterial supply of growth substances might produce benefits that would not be observed where a comparatively large amount is added at irregular intervals. Mixtures of such substances, produced by the bacteria, might also be of more benefit than individual materials. The fact that some Soviet workers have reported increased growth from sterile bacterial filtrates is in agreement with the growth-accelerator hypothesis. Also in harmony with this explanation is the fact that many plants will make the largest growth if growth always proceeds at the maximum rate. Even temporary growth retardation often results in a somewhat stunted plant. Growth regulators, produced by rhizosphere bacteria, may help to prevent such stunting.

It should be pointed out that apparently most soil microbiologists in the United States are inclined to discount the Soviet results. Jensen (50) in Aus-

tralia seems to hold views similar to those of the American workers. Although some of the Soviet experiments were evidently planned to be little more than field demonstrations, it should be emphasized that a considerable percentage of the work appears to have been well planned and adequately replicated. Many of the results can be subjected to the analysis of variance method or, in fact, are so positive that no such mathematical treatment is needed to show significance. Under these conditions the writer prefers to wait for the results from further experimentation before either accepting or discarding the Soviet claims.

## SUMMARY

This review of inoculation experiments with free-living bacteria deals briefly with early investigations and gives more detailed consideration to recent work reported chiefly from the USSR. It is pointed out that most of the early work gave negative results, and at the time the Soviet work was started (1925–1928) the use of Azotobacter as a seed inoculant was generally considered of no practical value. Much of the work in the USSR has, however, been positive and has led to an extensive use in that country of such inoculants.

Although there is no agreement among the Soviet scientists as to the reasons for the beneficial effects reported, three main ideas have been advanced. These are: (a) nitrogen is fixed by the bacteria living in the rhizosphere largely on the root excretions; (b) the added bacteria protect the higher plant against pathogenic microorganisms either by discouraging their growth or by destroying them; and (c) the bacteria stimulate plant growth through the production of auxins, hormones, vitamins, and other growth accelerators or regulators. A critical consideration of these ideas leads to the conclusion that, if inoculation with Azotobacter is beneficial, the effect is not likely to be due either to nitrogen fixation or to the effect on disease organisms. The auxin-hormone explanation seems more plausible, but at present there are few data to support such a claim.

The review emphasizes the need for well-planned experiments to establish with certainty whether inoculation with Azotobacter is beneficial and, if so, the exact conditions that lead to beneficial results. Until such additional information is available it is well to adopt a very conservative attitude with respect to the Soviet claims.

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*Annual Review of Biochemistry.* Volume 16. Edited by J. M. LUCK. Annual
Reviews, Inc., Stanford University, California, 1947. Pp. 740. Price $6.

This volume contains comprehensive reviews of recent developments in 25
fields of research in biochemistry. Each review is written by a specialist in the
field covered. For those primarily concerned with soil-plant science, the fol-
lowing subjects are of special interest: biological oxidations and reductions by
L. Michaelis, phosphorus compounds by W. W. Umbreit, mineral metabolism
by L. A. Maynard and S. E. Smith, the nitrogenous constituents of plants by
F. C. Steward and H. E. Street, mineral nutrition of plants by H. Lundegårdh,
growth substances in higher plants by F. Skoog, and use of isotopes in bio-
chemical research by M. D. Kamen. Each article is followed by 100 to 250
references. The editor is to be congratulated on the quality of papers presented.

*The Causes and Effects of Sedimentation in Lake Decatur.* By CARL B. BROWN,
J. B. STALL, AND E. E. DeTURK. Bulletin 37, Department of Registration
and Education, State Water Survey Division, Urbana, Illinois, 1947. Pp. 62.

This very illuminating publication deals with the problem of decreasing
water-storage capacity and increasing water consumption, with the inevitable
consequence of an expected water shortage whenever a bad drouth year re-
occurs. The study shows that sedimentation is a troublesome problem in
storage reservoirs. It calls for such remedial measures as raising present dams,
constructing up-stream reservoirs, and establishing soil conservation practices.
The 20 per cent increase in the average rate of sedimentation in 1936–1946,
as compared to the preceding 14 years, is credited to the increasing intensity in
the use of surrounding land for intertilled row crops. It is estimated that a
well-developed soil conservation program would reduce sedimentation 65 per
cent and materially raise the level of crop production.

*The Chemical Composition of Foods.* By R. A. McCANCE AND E. M. WIDDOW-
SON. Chemical Publishing Company, Inc., Brooklyn, 1947. Pp. 156.
Price $3.75.

The purpose of this book is to record the protein, fat, available carbohydrate,
Na, K, Ca, Mg, Fe, Cu, P, S, and Cl content of foods, condiments, and bever-
ages, and a very large part of the book is filled with such analyses. The data
are presented in terms of milligrams per 100 gm. and milligrams per ounce.
Analyses for cooked dishes containing several ingredients, and the recipes by
which they were made, are also shown. Special consideration is given to the
content of phytic acid P and the acid-base balance of foods.

*Colloid Science.* A Symposium. Chemical Publishing Co., Inc. Brooklyn,
New York, 1947. Pp. 208, figs. 32. Price $6.

The papers included in this volume are based on a postgraduate course that
was sponsored by the department of colloid science, Cambridge University.

The main headings include surface chemistry and colloids, thermodynamics and colloidal systems, study of macromolecules by ultracentrifuge, electrophoresis and diffusion measurements, viscosity of macromolecules in solution, kinetic theory of high elasticity, emulsions *in vivo*, study of colloidal systems by x-ray analyses, membrane equilibrium, infrared spectra and colloids, and vinyl polymerization in the liquid phase.   Colloidal chemists will find the book of considerable interest and value.

*Commercial Fertilizers, Their Sources and Use.*   Fourth edition.   By GILBEART
   H. COLLINGS.   The Blakiston Co., Philadelphia, 1947.   Pp. 522, figs. 160.
   Price $4.50.
This fourth edition was made necessary by the many developments in the fertilizer industry during the war period.   The general outline is the same as that of the third edition.   The 18 chapters deal with the early history of the fertilizer industry, source and manufacture of all the important fertilizer materials, problem of minor elements, adjusting soil reaction and fertilizer practice to crop requirements, and principles underlying the purchase and use of fertilizers.   A bibliography of some 700 references is appended.   The book has grown in value with each new edition until it is now probably the best in its field.

*Diagnosis and Improvement of Saline and Alkaline Soils.*   By L. A. RICHARDS
   and 7 contributing authors.   U. S. Department of Agriculture Regional
   Salinity Laboratory, Riverside, California, 1947.   Pp. 157, figs. 12.
This is a comprehensive report on recent studies on the origin and nature of saline and alkaline soils, methods for determining the amount and nature of the soluble salts, properties of soils in relation to these salts, and methods of diagnosis, improvement, and management of such soils.   Some 18 pages of figures and tables are appended.   Research specialists who are concerned with soils in relation to crop production will find this publication of great interest.

*Fungi.*   By FREDERICK A. WOLF AND FREDERICK T. WOLF.   John Wiley &
   Sons, Inc., New York, 1947.   Volume 1, pp. 438, figs. 153, price $6.   Volume
   2, pp. 538, figs. 82, price $6.50.
The authors of these two volumes have performed a prodigious task in assembling a wealth of excellent material and arranging it in a form that permits of ready reference to the information desired.   The first volume deals with the morphology and taxonomy of fungi and is complete in itself.  The second volume has to do with the metabolic and reproductive activities of fungi and the extent to which these are modified by environment.   The material in the second volume is of considerably greater value to the soil scientist than that in volume 1. The chapters on the nutrition of fungi and on their enzymic activities and biochemistry, those on the effects of radiation and the substrate reaction upon fungi, and those on the mycorrhizae, soil fungi, and fossil fungi are of special interest to him.   Volume 1 contains reference to the publications of some 600 workers in this field, and volume 2 to some 1000 others with, of course, a certain amount of duplication.

*Land Classification in the West Midland Region.* By The West Midland Group on Post-War Construction and Planning. Faber and Faber, Limited, London, 1947. Pp. 47, figs. 22. Price 12/6.

The need for this study arose from the fact that urbanization of the English countryside was proceeding at a rapid rate and without reference to proper use of the land. The committee took it for granted that, for the most part, the claims of agriculture to the best farming land were paramount. Accordingly, a detailed scheme of land classification, based on field-by-field examination, was undertaken. Fertility was judged by factors of site and soil rather than by productivity of the land under existing conditions. The concepts and techniques of this study should be of interest to all concerned with land use.

*Manual on Fertilizer Manufacture.* By VINCENT SAUCHELLI. The Davison Chemical Corporation, Baltimore, 1947. Pp. 126, figs. 31. Price $4.

The book was "prepared for the instruction of candidates chosen for training in supervisory positions in fertilizer plants and for the not too well technically trained who want to know more about fertilizer manufacturing procedures." Its four parts deal with plant-food elements and properties of mixed fertilizers, materials from which mixed fertilizers are made, compounding processes and problems, and miscellaneous data and statistics pertinent to the fertilizer industry. The book meets a definite need and will be found useful for reference.

*Microbial Antagonisms and Antibiotic Substances.* Second edition. By SELMAN A. WAKSMAN. The Commonwealth Fund, New York, 1947. Pp. 415, figs. 33. Price $4.

This second edition attempts to bring the reader up to date on this rapidly growing phase of microbiological science. It deals with the soil as the starting point in the destruction of plant and animal pathogens, the isolation and cultivation of the microorganisms that effect this, the chemical nature of the antibiotic substances they produce, and the use of these antibiotics for disease control. The final chapter gives a glimpse of future developments in this field. Although the book is intended primarily for scientists who are engaged in the study of antibiotics, much of the material is of interest to the layman who wants to be better informed on the highly important subject.

*Permafrost.* Second printing. By SIEMON WILLIAM MULLER. J. W. Edwards, Inc., Ann Arbor, Michigan, 1947. Pp. 231, figs. 87.

This is a lithoprinted republication of material prepared under the direction of the Military Division Office, Chief of Engineers, U. S. Army. The book deals with permanently frozen ground and engineering problems related thereto. The first section includes definitions and a discussion of origin, geography, thickness, climatic effects, degradation, hydrology, and physical and mechanical effects of permanently frozen ground, and its effect on vegetation. The remainder of the book is devoted to engineering problems and investigations of frozen ground in connection with these problems. The glossary contains 11 pages of definitions, 6 pages of references, and a conversion table of measures.

*Practical Emulsions.* Second edition. By H. BENNETT. Chemical Publishing Co., Inc., Brooklyn, 1947. Pp. 556, figs. 9. Price $8.50.

The second edition contains not only revised material from the first edition but considerable supplemental material. A symposium on emulsifying agents and emulsions makes up two new chapters. Some additional material on fatty acid esters of polyhydric alcohols and on lecithin and pectin has been included. Important references are appended to each chapter. The book is intended primarily for industrial use, but much of the material is of considerable value to those engaged in the several lines of agricultural research.

*Rocks and Rock Minerals.* Third edition. By LOUIS V. PIRSSON AND ADOLPH KNOPF. John Wiley & Sons, Inc., New York, 1947. Pp. 349, figs. 72, plates 36. Price $4.

A period of 22 years has passed since the second revision of this popular textbook on rocks and their minerals was published. As a result of developments in this field of science during this period, it became necessary to make many changes in the book. These include a reclassification of igneous rocks, a revised treatment of the metamorphic group, and inclusion of considerably more analytical data. Special pains were taken to make the material more readable and more readily understandable. This is an excellent book that merits a place on every soil scientist's shelf.

*Symposium on pH Measurement.* Technical Publication 73, American Society for Testing Materials, Philadelphia, 1947. Pp. 79. Price $1.50.

This publication consists of a series of eight papers on pH measurement and discussion related thereto. The papers were presented at the 49th annual meeting of the American Society for Testing Materials, held in Buffalo, New York, June 27, 1946. The purpose of the symposium was to consider the more recent theories and practices in the measurement of pH values by colorimetric and potentiometric procedures. The papers deal with the hydrogen electrode and calomel cell, extension of acidity scale to nonaqueous systems, buffer solutions, glass electrodes, precautions in colorimetric determinations, and acid-base equilibriums in aqueous and nonaqueous solutions.

*Viruses and Virus Diseases of Plants.* By MELVILLE THURSTON COOK. Burgess Publishing Company, Minneapolis, 1947. Pp. 244. Price $4.10.

This is an excellent review of the literature on viruses and the diseases associated with them. It includes reviews of the theories as to causes of virus diseases, nature and properties of plant viruses, reaction of host plants to viruses, transmission of viruses, and control of virus diseases of plants. The bibliography includes about 1,000 references. This publication is of interest not only to plant pathologists but to plant physiologists and to soil scientists as well. The book is lithoprinted and bound in light cardboard.

The Editors.

# INFLUENCE OF SOME CROPPING AND FERTILIZING PRACTICES ON THE URONIDES OF SOIL[1]

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Received for publication June 16, 1947

A considerable fraction of the organic carbon in surface soil appears to be uronic. The percentage of uronic carbon in organic matter varies in different soils. The reason for this variation is not known. Since the uronides appear to be of microbial origin (3), it seems logical to suspect, however, that factors such as climate, vegetation, and parent material that influence the nature and activity of the soil flora also influence the composition and content of the uronic constituents of organic matter. Little information regarding the influence of the aforementioned factors on the uronic constituents of soil was furnished by determining the apparent uronic carbon content of a number of different soil types from a wide area (2) partly because too many variables were involved and partly because no one factor appeared to be dominant. The data on samples of a single soil type, Cheyenne fine sandy loam, however, indicated that inspite of wide variations in clay content and organic carbon the proportion of the uronic carbon to total carbon remained rather stable. Whether or not this proportion would remain so constant under the influence of different types of vegetation is not known, since the vegetation was the same on all plots. It is conceivable, though, that plant materials may affect the quantity as well as the quality of the uronides in soil organic matter in two different ways; namely, by influencing the nature and activity of the soil flora that supplies uronides and by furnishing uronides directly to soils. The latter seems less probable than the former (3).

Waksman and Reuszer (4) suggested that fertilizer treatments may indirectly influence the uronide content of soil organic matter. They found less uronic carbon in limed and manured than in untreated Sassafrass soil. It was reasoned that the fertilizer treatments made conditions more favorable for microbial activity and attack on the uronides. If the view is accepted that the uronides in soils are of microbial origin it is difficult to see why conditions favoring an increase in the activity of the soil flora should necessarily result in a decrease in the uronic constituents.

Before the uronic constituents of soil organic matter can be properly evaluated in agronomic terms, information as to the influence of different types of vegetation on the amount and nature of these constituents must be available. This paper reports the results of an investigation undertaken to obtain such information. The influence of long-time single cropping, crop rotation systems, and fertilizing practices on the quantity of uronic carbon and rate of decarboxylation of the uronic groups in soils is reported.

Soils from six different states taken[2] from plots that had been planted to a single crop continuously for many years are described in table 1.

Carbon determinations were made by the dry combustion method (1, pp. 3–4). Uronic carbon was determined according to the method previously described (2).

## EXPERIMENTAL RESULTS

### Long-time single cropping

The influence of long-time single cropping on the total and uronic carbon content is indicated in table 2. The greatest proportion of total organic carbon that was uronic was found in the soils cropped continuously to corn, although for any one soil type the corn plots had the least total carbon content. The continuous grass plots, on the other hand, were found to have the lowest proportion of uronic carbon to total carbon and the highest amount of total carbon. The proportion of uronic to total carbon was only slightly lower in the plots cropped to small grains than in those planted to corn. For the most part, however, the original ratio of uronic to total carbon of a given soil was not greatly changed as a result of cropping. Greater differences in the ratio were found to exist between different soil types than between samples from any single soil type.

### Long-time crop rotations

Although the long-time crop rotation practices on Clarion loam, Hillsdale silt loam, and Wheeling silt loam failed to maintain the total carbon content of the soils at their original level, the cropped soils possessed a slightly higher ratio of uronic to total carbon than the original soils (table 3). The presence of legumes in the rotations on Clarion loam appeared to result in less loss of total organic carbon than when legumes were not included. Furthermore, the total yield of uronic carbon in the cropped soil, when legumes were included in the rotation, was as great as, if not slightly greater than, in the original soil.

### Fertilizer treatment

To study the influence of treatments of manure, phosphorus, and lime on the relationship between uronic and total carbon, soil samples taken from fertilized and unfertilized plots that had similar long-time cropping practices were analyzed

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| SOIL TYPE | LOCATION | FIELD | PLOT | CROP | YEARS GROWN | FERTILIZER TREATMENT |
|---|---|---|---|---|---|---|
| Brown silt loam | Urbana, Illinois | Morrow | ...... | Virgin sod | .. | None |
| | | | ...... | Corn | 70 | None |
| | | | ...... | Grass | 50 | None |
| Brookston silt loam | Lafayette, Indiana | Experiment Farm | ...... | Virgin forest | .. | None |
| | | | 43 | Corn | 30 | 100–200 lbs. 0-12-12 annually |
| | | | 40 | Oats | 30 | 200 lbs. 2-12-6 annually |
| | | | ...... | Alfalfa | 30 | None |
| | | | 39 | Wheat | 30 | 200 lbs. 2-12-6 annually |
| | | | ...... | Grass | 31 | None |
| Putnam silt loam | Columbia, Missouri | Sanborn | 17 | Corn | 57 | None |
| | | | 18 | Corn | 57 | 6 tons manure annually |
| | | | 9 | Wheat | 57 | None |
| | | | 10 | Wheat | 57 | 6 tons manure annually |
| | | | 23 | Timothy | 57 | None |
| | | | 22 | Timothy | 57 | 6 tons manure annually |
| Dunmore silt loam | Blacksburg, Virginia | Blacksburg | 1 | Corn | 32 | None |
| | | | 2 | Corn | 32 | 6 tons manure every 4 years 219 lbs. raw rock P annually |
| | | | 3 | Wheat | 32 | None |
| | | | 4 | Wheat | 32 | MP,* as above |
| | | | 5 | Clover | 32 | None |
| | | | 6 | Clover | 32 | MP, as above |
| | | | 7 | Grass | 32 | None |
| | | | 8 | Grass | 32 | MP, as above |
| Palouse silt loam | Pullman, Washington | College Farm | ...... | Virgin sod | .. | None |
| | | | C14 | Corn | 25 | None |
| | | | 1A | Wheat | 25 | None |
| | | | 3A | Wheat-Fallow | 25 | None |
| Hillsdale silt loam | Lansing, Michigan | College Farm | 1 | Virgin timber | .. | None |
| | | | 2 | Virgin timber | .. | None |
| | | | 3 | Corn-Wheat | 16 | Lime |
| | | | 4 | Corn-Wheat | 16 | Lime |
| Wheeling silt loam | Lakin, West Virginia | Lakin Farm | ...... | Bluegrass roadway | .. | None |
| | | | 36E | Corn 12 years-clover 10 years | 22 | Phosphate + lime |
| | | | 40E | Corn, soybeans, wheat, clover and timothy | 22 | Phosphate + lime + legume cover crop |
| | | | 122D | Corn + soybeans-wheat | 22 | Phosphate + lime, no cover crop |
| Clarion loam | Ames, Iowa | Agronomy Farm | 910 | Corn | 32 | None |
| | | | 906 | Corn | 32 | None |
| | | | 908 | Corn | 32 | Manure + lime + phosphate |
| | | | 810 | Corn-oats | 32 | None |
| | | | 816 | Corn-oats | 32 | None |
| | | | 817 | Corn-oats-clover | 32 | None |
| | | | 1005 | Corn-oats-clover-wheat/alfalfa (5 years) | 32 | None |
| | | | 1004 | Same as plot 1005 | 32 | Manure + lime + phosphate |
| Webster silt loam | Ames, Iowa | Agronomy Farm | 1305 | Corn-corn-oats-clover | 32 | None |
| | | | 1306 | Corn-corn-oats-clover | 32 | Lime + 16 tons manure |

for uronic carbon. The data in tables 2 and 3 show that applications of manure, phosphorus, and lime to soils assisted in maintaining the total and uronic carbon at a higher level than when no fertilizer was added, although the proportion of

TABLE 2

*Influence of long-time single cropping on uronic and total carbon content of various surface soils*

| LOCATION AND SOIL TYPE | CROP* | YEARS CROPPED | TOTAL CARBON | URONIC CARBON | URONIC CARBON/ TOTAL CARBON |
|---|---|---|---|---|---|
| | | | *per cent* | *per cent* | *per cent* |
| Illinois, Brown silt loam | Virgin sod | 0 | 3.2 | 0.52 | 16 |
| | Corn | 70 | 1.8 | 0.31 | 17 |
| | Grass | 50 | 4.6 | 0.60 | 13 |
| Indiana, Brookston silt loam | Virgin forest | 0 | 2.6 | 0.42 | 16 |
| | Corn | 30 | 1.8 | 0.34 | 19 |
| | Oats | 30 | 2.5 | 0.43 | 18 |
| | Alfalfa | 30 | 2.2 | 0.38 | 17 |
| | Wheat | 30 | 2.2 | 0.34 | 16 |
| | Grass | 31 | 3.1 | 0.44 | 14 |
| Iowa, Clarion loam | Original 1914 | .. | 1.5 | 0.23 | 15 |
| | Corn 1946 | 32 | 1.2 | 0.21 | 19 |
| | Original 1914 | .. | 2.4 | 0.32 | 13 |
| | Corn 1946 | 32 | 2.0 | 0.29 | 15 |
| | Original 1914 | .. | 2.4 | 0.37 | 15 |
| | Corn + MLP 1946 | 32 | 1.8 | 0.25 | 14 |
| Missouri, Putnam silt loam | Corn | 57 | 0.8 | 0.19 | 24 |
| | Corn + M | 57 | 1.2 | 0.28 | 23 |
| | Wheat | 57 | 0.9 | 0.18 | 20 |
| | Wheat + M | 57 | 1.5 | 0.31 | 20 |
| | Timothy | 57 | 1.5 | 0.29 | 19 |
| | Timothy + M | 57 | 1.8 | 0.35 | 19 |
| Virginia, Dunmore silt loam | Corn | 32 | 0.5 | 0.20 | 40 |
| | Corn + MP | 32 | 0.7 | 0.24 | 34 |
| | Wheat | 32 | 0.7 | 0.23 | 35 |
| | Wheat + MP | 32 | 0.8 | 0.31 | 38 |
| | Clover | 32 | 0.9 | 0.30 | 35 |
| | Clover + MP | 32 | 1.0 | 0.34 | 33 |
| | Grass | 32 | 1.5 | 0.35 | 23 |
| | Grass + MP | 32 | 1.7 | 0.38 | 23 |
| Washington, Palouse silt loam | Virgin sod | 0 | 1.8 | 0.35 | 19 |
| | Corn | 25 | 1.2 | 0.24 | 20 |
| | Wheat | 25 | 1.3 | 0.25 | 19 |
| | Wheat + fallow | 25 | 1.4 | 0.26 | 19 |

*M = manure, L = lime, P = phosphate.

uronic to total carbon of a given soil with like cropping history was little influenced by the various fertilizer treatments. Even heavy applications of manure failed to change the ratio appreciably.

## Relationship between total and uronic carbon

It is quite apparent from the analyses of total and uronic carbon that as the total carbon increased the uronic carbon also increased. What is not clearly shown by the data in tables 2 and 3 is the rate of change of uronic carbon as the total carbon changed. For this reason the percentage of uronic carbon in the various samples was plotted against the percentage of total carbon, and the linear

### TABLE 3

*Influence of long-time crop rotations on uronic and total carbon content of some surface soils*

| LOCATION AND SOIL TYPE | CROP | YEARS CROPPED | TOTAL CARBON | URONIC CARBON | URONIC CARBON/ TOTAL CARBON |
|---|---|---|---|---|---|
| | | | *per cent* | *per cent* | *per cent* |
| Iowa, Clarion loam | Original | .. | 2.5 | 0.35 | 14 |
| | Corn-oats | 32 | 1.6 | 0.28 | 18 |
| | Original | .. | 2.0 | 0.32 | 16 |
| | Corn-oats | 32 | 1.5 | 0.24 | 16 |
| | Original | .. | 1.9 | 0.28 | 15 |
| | Corn-oats-clover | 32 | 1.6 | 0.30 | 19 |
| | Original | .. | 2.7 | 0.38 | 14 |
| | Corn-oats-clover-wheat-4 years/alfalfa-5 years | 32 | 2.1 | 0.35 | 17 |
| | Original | .. | 2.7 | 0.36 | 13 |
| | Corn-oats-clover-wheat-4 years*/alfalfa-5 years | 32 | 2.4 | 0.38 | 16 |
| Iowa, Webster silt loam | Corn-corn-oats-clover | 32 | 3.2 | 0.41 | 13 |
| | Corn-corn-oats-clover† | 32 | 3.8 | 0.48 | 13 |
| Michigan, Hillsdale silt | Virgin timber | None | 4.2 | 0.45 | 11 |
| | Corn-wheat | 16 | 0.9 | 0.15 | 17 |
| West Virginia, Wheeling silt loam | Grass sod | .. | 1.1 | 0.28 | 25 |
| | Corn/12 years-clover/10 years‡ | 23 | 0.8 | 0.23 | 29 |
| | Corn-soy-wheat‡ | 23 | 0.8 | 0.22 | 27 |
| | Corn-soy-wheat-clover-timothy‡ | 23 | 0.9 | 0.22 | 25 |

\* Manure, lime, phosphate.
† Manure, lime.
‡ Phosphate, lime.

regression of uronic carbon $y$ on total carbon $x$ was calculated (fig. 1). Total carbon was considered to be measured independently and without error. The linear regressions for the various soil samples from the different locations indicate that the rate of change of uronic carbon as the total carbon changed was similar for the different soils, although the mean proportion of uronic to total carbon was different in different soils. For example, the rate of change in uronic carbon per unit change in total carbon is about the same in the original Clarion loam and the

FIG. 1. RELATIONSHIP BETWEEN TOTAL ORGANIC AND URONIC CARBON CONTENT OF
CROPPED AND ORIGINAL SOILS FROM VARIOUS AREAS



FIG. 2. LINEAR REGRESSION OF URONIC CARBON ON TOTAL ORGANIC CARBON—POOLED
DATA FROM ALL LOCATIONS

TABLE 4

*Evolution of uronic carbon of various virgin soils and soils planted to single crops continuously for 25 or more years*

| LOCATION AND SOIL TYPE | CROP* | Preheating 0.25 hr. | SUMMATION OF URONIC CARBON-PER CENT OF TOTAL EVOLVED | | | | | | | CARBON EVOLVED SOIL PER GRAM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Boiling period | | | | | | | |
| | | | 0.50 hr. | 0.75 hr. | 1.00 hr. | 2.50 hr. | 2.50 hrs. | 5.00 hrs. | 7.00 hrs. | |
| | | | | | | | | | | *mgm.* |
| Illinois, Brown silt loam | Virgin sod | 1 | 16 | 23 | 29 | 40 | 61 | 89 | 100 | 26 |
| | Corn | 2 | 20 | 28 | 32 | 40 | 57 | 84 | 100 | 15 |
| | Grass | 1 | 13 | 25 | 32 | 44 | 65 | 90 | 100 | 29 |
| Indiana, Brookston silt loam | Virgin forest | 1 | 20 | 28 | 34 | 45 | 62 | 88 | 100 | 21 |
| | Corn | 1 | 23 | 30 | 35 | 46 | 62 | 87 | 100 | 17 |
| | Oats | 1 | 21 | 28 | 33 | 45 | 59 | 87 | 100 | 21 |
| | Alfalfa | 2 | 17 | 24 | 28 | 39 | 56 | 86 | 100 | 19 |
| | Wheat | 1 | 23 | 30 | 35 | 45 | 59 | 85 | 100 | 17 |
| | Grass | 1 | 18 | 25 | 32 | 43 | 62 | 89 | 100 | 22 |
| Iowa, Clarion loam | Original | 1 | 16 | 22 | 27 | 36 | 52 | 82 | 100 | 11 |
| | Corn | 1 | 15 | 21 | 25 | 35 | 49 | 78 | 100 | 11 |
| | Original | 1 | 13 | 20 | 26 | 34 | 53 | 82 | 100 | 16 |
| | Corn | 1 | 16 | 20 | 25 | 33 | 50 | 81 | 100 | 14 |
| | Original | 1 | 21 | 27 | 32 | 41 | 56 | 85 | 100 | 18 |
| | Corn + MLP | 1 | 15 | 21 | 27 | 36 | 52 | 82 | 100 | 12 |
| Missouri, Putnam silt loam | Corn | 2 | 24 | 29 | 34 | 40 | 55 | 83 | 100 | 9 |
| | Corn + M | 2 | 22 | 28 | 33 | 42 | 57 | 84 | 100 | 13 |
| | Wheat | 3 | 26 | 31 | 36 | 43 | 57 | 85 | 100 | 9 |
| | Wheat + M | 2 | 20 | 26 | 31 | 40 | 56 | 84 | 100 | 15 |
| | Timothy | 2 | 19 | 25 | 30 | 40 | 57 | 87 | 100 | 14 |
| | Timothy + M | 1 | 19 | 26 | 32 | 41 | 59 | 88 | 100 | 17 |
| Virginia, Dunmore silt loam | Corn | 1 | 29 | 36 | 40 | 47 | 62 | 86 | 100 | 10 |
| | Corn + MP | 1 | 22 | 28 | 33 | 43 | 60 | 86 | 100 | 12 |
| | Wheat | 1 | 22 | 27 | 31 | 39 | 54 | 83 | 100 | 11 |
| | Wheat + MP | 1 | 23 | 29 | 33 | 41 | 56 | 86 | 100 | 14 |
| | Clover | 1 | 23 | 30 | 35 | 43 | 58 | 85 | 100 | 14 |
| | Clover + MP | 1 | 25 | 32 | 37 | 45 | 60 | 85 | 100 | 16 |
| | Grass | 1 | 26 | 32 | 37 | 46 | 62 | 86 | 100 | 17 |
| | Grass + MP | 1 | 27 | 33 | 39 | 48 | 63 | 87 | 100 | 19 |
| Washington, Palouse silt loam | Virgin sod | 1 | 13 | 20 | 26 | 37 | 53 | 87 | 100 | 17 |
| | Corn | 1 | 13 | 20 | 26 | 34 | 48 | 80 | 100 | 12 |
| | Wheat | 2 | 15 | 22 | 29 | 39 | 55 | 87 | 100 | 12 |
| | Wheat + fallow | 1 | 15 | 21 | 26 | 36 | 50 | 81 | 100 | 13 |

* M = Manure, L = lime, P = phosphate.

cultivated Dunmore silt loam, but the mean ratio of uronic to total carbon is decidedly different.

When the linear regression of uronic carbon on total carbon was calculated from the pooled data of all the soil samples, the rate of change in uronic to total carbon was found to be somewhat less than that of the soils calculated individually, as

TABLE 5

*Evolution of uronic carbon of various original soils and soils planted for long periods to different crop rotation systems*

| LOCATION AND SOIL TYPE | CROP | SUMMATION OF URONIC CARBON-PER CENT OF TOTAL EVOLVED | | | | | | | | | CARBON EVOLVED PER GRAM SOIL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preheating 0.25 hr. | Boiling period | | | | | | | | |
| | | | 0.50 hr. | 0.75 hr. | 1.00 hr. | 1.50 hrs. | 2.50 hrs. | 5.00 hrs. | 7.00 hrs. | | |
| | | | | | | | | | | | *mgm.* |
| Iowa, Clarion loam | Original | 1 | 16 | 25 | 32 | 41 | 58 | 83 | 100 | | 17 |
| | Corn-oats | 1 | 14 | 19 | 24 | 32 | 48 | 77 | 100 | | 13 |
| | Original | 1 | 13 | 20 | 26 | 36 | 54 | 84 | 100 | | 16 |
| | Corn-oats | 1 | 15 | 20 | 25 | 33 | 50 | 82 | 100 | | 12 |
| | Original | 1 | 15 | 20 | 26 | 36 | 53 | 84 | 100 | | 14 |
| | Corn-oats-clover | 1 | 15 | 20 | 25 | 34 | 51 | 82 | 100 | | 15 |
| | Original | 1 | 13 | 19 | 24 | 34 | 52 | 83 | 100 | | 14 |
| | Corn-oats-clover wheat- 4 years*/alfalfa-5 years | 1 | 14 | 20 | 25 | 34 | 50 | 81 | 100 | | 17 |
| | Original | 1 | 15 | 21 | 27 | 36 | 53 | 82 | 100 | | 13 |
| | Corn-oats-clover wheat-4 years/alfalfa-5 years | 1 | 14 | 20 | 25 | 34 | 51 | 82 | 100 | | 18 |
| Iowa, Webster silt loam | Corn-corn-oats-clover | 1 | 14 | 20 | 26 | 36 | 54 | 87 | 100 | | 20 |
| | Corn-corn-oats-clover† | 1 | 14 | 21 | 27 | 38 | 57 | 89 | 100 | | 23 |
| Michigan, Hillside silt loam | Virgin timber | 1 | 26 | 37 | 43 | 57 | 72 | 92 | 100 | | 22 |
| | Corn-wheat | 3 | 26 | 34 | 41 | 51 | 67 | 90 | 100 | | 7 |
| West Virginia, Wheeling silt loam | Sod | 2 | .... | 34 | 39 | 46 | 60 | 85 | 100 | | 14 |
| | Corn/ 12 years-clover/10 years‡ | 2 | 23 | 42 | 47 | 54 | 66 | 88 | 100 | | 12 |
| | Corn-soy-wheat‡ | 2 | 23 | 35 | 40 | 48 | 61 | 85 | 100 | | 11 |

\* Manure, lime, phosphate.
† Manure, lime.
‡ Phosphate, lime.

may be seen by comparing the regression coefficients in figure 1 with the mean regression of all the soils in figure 2. For the sake of comparison it will be noted further that the linear regression coefficient of the pooled data and that of

Brookston silt loam of Indiana are about identical, being $0.082x$ and $0.089x$, respectively.

### Decarboxylation rate of uronic groups

Uronic groups from polyuronides of plants and soils may be distinguished from each other to a certain extent by the way they decarboxylate in the presence of boiling 12 per cent hydrochloric acid solution. Whether or not organic matter of various soil types or of soils treated differently can be distinguished by the same method has not been shown. Since uronic units of the various agricultural residues entering the soil each year do not necessarily decarboxylate at the same rate, it is logical to suspect that the plant residues would influence the decarboxylation rate of the uronic units of organic matter that is formed from these materials. On the other hand, if the uronic units of soils are not of plant origin but of microbial origin, the nature of the plant material entering the soil should have little if any direct influence on the decarboxylation rate of the uronides of the organic matter. Data in table 4, showing the rate of decarboxylation of uronic units of various virgin soils and soils planted to single crops continuously for 25 or more years, in general indicate that neither the nature of the crop nor the fertilizer treatment appreciably influenced the carbon dioxide evolution rate of a single soil type. This also appeared to hold true for soils planted for long periods to different crop rotation systems (table 5). Greater differences in the rate of decarboxylation of uronic units were observed between different soil types than between samples of the same soil.

### DISCUSSION

Even though the percentage of uronic carbon as well as the rate of decarboxylation of the uronic units usually differs for different plants and even for a single plant at different stages of maturity (2), neither the ratio of uronic to total carbon of one soil type nor the rate of decarboxylation of the uronic units was found to be influenced appreciably by different cropping practices. Furthermore, fertilizer applications that influenced the quantity of organic residues returned to the soil had no apparent influence on this proportion or the decarboxylation rate. The proportion of uronic to total carbon and the characteristic decarboxylation rate of the uronic units of soil organic matter differed to a greater degree among different soil types of like cropping histories than among samples of one soil type of unlike cropping histories.

The proportion of uronic to total carbon in samples of one soil type appears to be closely correlated with the total amount of carbon. In general, those soils that had the greatest amount of total carbon also yielded the greatest quantity of uronic carbon. However, as the original carbon content of a soil was reduced as a result of cropping there was a tendency for a greater proportionate loss of total organic carbon than uronic carbon. Those practices that resulted in the greatest loss of organic matter, such as cropping with continuous corn, also favored the formation of organic residues richer in uronides.

The two possible sources of uronides in soils are plant residues and products

of microorganisms. Presumptive evidence has been presented indicating that the soil uronides originate as microbial products (3). If higher plants contribute uronic constituents directly to soil organic matter it seems logical to suspect that these constituents would possess certain features that could be identified with the type of vegetation continually being produced on a soil. This, however, was not the case. Either the plant polyuronides were transformed during the decomposition process in such a manner as to lose their identity or they were completely destroyed by the soil flora and replaced by uronides synthesized by microorganisms. The latter suggestion appears to be better supported in view of the ready availability of plant polyuronides to rapid attack and complete decomposition by microorganisms.

If the view is accepted that the uronides are of microbial origin, then the nature of the uronic constituents of soils will depend largely upon those factors that influence the characteristics of the soil microflora. Vegetation appears to be eliminated as a major factor, inasmuch as the ratio of uronic to total carbon and the rate of decarboxylation of the uronic units could not be related to the nature of the crop continuously grown on a soil. The other main variable between the different soil types is environmental conditions. Since the nature of the uronic constituents appeared to be quite similar in a single soil type regardless of vegetation but varied considerably among different soil types, it is quite possible that the environmental conditions indirectly influenced the nature of the uronic constituents of soils by influencing the character and activity of the soil microflora.

## SUMMARY

The apparent uronic carbon content and decarboxylation rate of the uronic units in the surface soil of nine soil types that had been planted continuously to a single crop for 25 or more years or to a stable crop rotation are reported. The proportion of uronic to total carbon of a single soil type changed only slightly as a result of different cropping and fertilizer treatments. The changes appear to be more closely related to the total carbon content than to the nature of the crop or cropping system; the lower the total carbon content of a given soil, the higher the percentage of uronic carbon in the organic matter regardless of the crop.

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# TROPICAL SOILS IN RELATION TO PLANT NUTRITION

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Fertilizer practices based on methods of soil analysis commonly used in temperate zones often fail in the tropics. This is because the much more rapid rate of weathering in the moist, warm lands of the tropics sets free readily available plant nutrients that cannot be determined by these methods. It is not difficult to picture the degree of active weathering that takes place in the tropics when one considers that soil and water temperatures of 45 to 50° C. during the hottest time of the day are not exceptional.

The purpose of this paper is to show the importance of tropical weathering to plant life when the soil contains certain minerals and when it contains phosphoric acid of organic origin.

## MINERALS

### Biotite $[K_2O \cdot 4 (Fe_2Mg)O \cdot 2(Al_2Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O]$

If in the slightly weathered Toba rhyolitic soils of the East Coast of Sumatra the exchangeable K and Mg are determined by percolation with 0.5 $N$ NH$_4$Cl, 0.2 to 0.5 m. e. K and traces of Mg will be found per 100 gm. soil. The first quantity corresponds to approximately 280 to 700 kgm. K$_2$O per hectare, if the depth of the soil is taken as 30 cm. (the volume-weight of the soil is about 1). Judged by European standards, these soils should be very poor in K and Mg. This, however, is not the case, because no K or Mg deficiencies appear and, in field experiments, no additional yield is obtained from potash fertilization. This is true even after prolonged occupation by exhausting crops, such as sisal (*Agave sisalana*), which withdraws from the soil about 300 kgm. K$_2$O and 125 kgm. MgO per hectare per year.

After one extraction with 25 per cent HCl, however, 0.15 to 0.20 per cent K$_2$O and 0.05 to 0.10 per cent MgO are found. These figures are equivalent to 4,500 to 6,000 kgm. K$_2$O and 1,500 to 3,000 kgm. MgO per hectare. Strong extraction dissolves much of the biotite occurring in the Toba rhyolitic soils. Repeated extraction will dissolve it completely.

In the more weathered rhyolitic soils, little biotite remains, and plants like sisal that need high concentrations of nutrients show symptoms of K and Mg deficiency. On the other hand, oil palms grow satisfactorily because this crop requires only 150 kgm. K$_2$O and 50 kgm. MgO per hectare per year to develop its bunches. In strongly weathered soils almost completely depleted of biotite, even oil palms suffer from K and Mg deficiency.

### Bytownite (1 albite + 4 anorthite) and basic volcanic glass

The andesitic ash soils of the Kloet volcano in Java, where a so-called "basic" stone occurs, are very rich in Ca. This is in the form of the feldspathic mineral bytownite, augite $[CaO \cdot 2(MgFe)O \cdot (AlFe)_2O_3 \cdot 3SiO_2]$, and volcanic glass.

Analysis reveals that these ash soils contain only a few milliequivalents of exchangeable Ca per 100 gm., corresponding to about 1,700 kgm. CaO per hectare. Ca deficiency is not observed, however, in the rubber, coffee, and sugarcane plantations on these soils. Nor are higher yields obtained in field experiments when lime is added, even after growth for years of a plant like sisal that requires about 400 kgm. CaO a year.

Extraction of the soil with 25 per cent HCl dissolves 1 to 2 per cent CaO, corresponding to approximately 30,000 to 60,000 kgm. CaO per hectare. This comes mainly from the very readily weathering "basic" feldspar (bytownite) and the "basic" volcanic glass.

### *Hypersthene* [$(MgFe)O \cdot SiO_2$]

The andesitic ash soils of the Kloet volcano also contain a good deal of Mg in the form of hypersthene and augite. The former is especially subject to weathering because of the cavities occurring in the minerals even in slightly weathered soils.

If the exchangeable Mg in the sandy Kloet soils is determined, only traces to about 0.1 m.e. Mg per 100 gm. soil are found. These results correspond to about 60 kgm. MgO per hectare. According to temperate-zone standards the figure is very low, and one would be inclined to apply Mg fertilizer. Typical Mg deficiency symptoms are not observed in the fields, however, even when sisal has been grown for many years.

On extraction of the soil with 25 per cent HCl, as much as 0.5 per cent MgO is found, corresponding to about 1,500 kgm. per hectare. These high figures are due mainly to the Mg of the hypersthene. Apparently this mineral yields enough Mg, under tropical conditions, even for plants of high Mg requirement.

### *Amphibole* [$Ca_3Na_2(MgFe) \cdot 8(AlFe)_4 \cdot Si_{14}O_{44}$]

The "acid" volcanic Toba rhyolite itself contains little lime. This occurs in the form of the mineral amphibole.

Analysis of tropical forest soils reveals that the adsorption complex consists almost entirely of lime. This lime comes from the leaves that decompose on the surface of the soil. It has been brought up from the subsoil during centuries by the forest vegetation.

After the forest is cleared, the humus content of the sandy Toba rhyolitic soils soon falls to about 1 per cent, when determined by the Itcherikov method. At this stage the CaO content is about 0.5 m.e. per 100 gm. soil and 0.030 per cent soluble in 25 per cent HCl. These figures correspond to about 400 and 900 kgm. CaO per hectare. The pH falls from about 7 to 4.[1] According to temperate-zone standards these soils would be decidedly in need of Ca. But Ca-deficiency symptoms do not appear in the plantations at this stage in which the soil probably is not yet thoroughly decomposed, from a geological point of view,

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[1] In the adsorption complex of the Toba rhyolitic soils rich in manganese (0.2 to 0.6 per cent $Mn_3O_4$ soluble in 25 per cent HCl) manganese replaces calcium and potassium as weathering proceeds. This may go so far that 60 per cent of the exchangeable ions consist of manganese.

and it is still possible to obtain maximum harvests without applying fertilizers. Apparently enough Ca becomes available through decomposition of the amphibole for oil, palm, tea, and rubber plants. Crops having very high lime requirements, however, such as sisal, do show Ca-deficiency symptoms.

### Andesine (3 albite + 2 anorthite)

The clayey andesinic soils of the coastal regions of Java have been planted to sugarcane for centuries. Rarely do K-deficiency symptoms occur here before the soil is strongly weathered.[2]

When the amount of exchangeable K is determined by percolation with 0.5 $N$ NH$_4$Cl solution, the results show 0.7 to 1 m.e. per 100 gm. of soil, corresponding to approximately 1,000 to 1,400 kgm. K$_2$O per hectare. These figures are higher than those for the sandy rhyolitic soils of the East Coast of Sumatra, but the latter have an adsorption capacity of only about 10 m.e., whereas the heavy clay soils of Java have an adsorption capacity of 20 to 30 m.e.

If the andesitic clay soils are extracted with 25 per cent HCl, only a little more K is found, that is, about 0.05 per cent, corresponding to 1,200 to 1,500 kgm. K$_2$O per hectare. This is a rather small amount, in view of the K needs of sugarcane—200 to 250 kgm. K$_2$O per hectare. The reason is that the andesitic soils still contain a fairly large amount of andesine. This mineral dissolves with difficulty in concentrated HCl, but it apparently gives off enough K to the plant through weathering in the tropical climate. Only when the soils are weathered more strongly and when the plant has high requirements, like sisal, do typical deficiency symptoms eventually appear in the plantations.

### Stage of weathering

It is clear, then, that under tropical conditions certain minerals can be important sources of nutrients to the plant. Not only the minerals that occur in a special type of soil, but also the stage of weathering of the soil, must be considered, for, if a soil is so thoroughly weathered that all readily decomposing minerals have been eliminated from it, it matters little to the plant what the origin of the soil may be. Furthermore, if the rock in question has only a small inherent content of nutrients, deficiency symptoms will appear in crops at a less advanced stage of weathering.

Table 1 shows the minerals occurring in the so-called "heavy" fraction of soil at certain stages of weathering.[3] The percentages given for each stage of decomposition represent the mean of 10 soils.

These figures show that the very strongly weathered soils, which are represented by the so-called "yellow" semisubhydric rhyolitic soils of the East Coast of Sumatra, consist almost entirely of allanite and zircon, which are very resistant to decomposition. These soils contain many Fe-Mn concretions (Fe$_2$O$_3$, 19 per

[2] In these low coastal regions irrigation water contains virtually no nutrients, because these are retained in the uplands or in the immediate vicinity of the water-supply canals.

[3] According to Edelman, C. H. Petrologische Provincies in het Nederlandsche Kwartair. Thesis, Amsterdam, 1933. See also: Marel, H. W. van der. Onderzoek omtrent het voorkomen van de mineralen orthiet en zirkoon in de liparietgrondenv an Sumatra's O-kust. *Ingenieur in Nederland.-Indië* 8: 33–38. 1941.

cent; $Al_2O_3$ + $TiO_2$, 15 per cent; and $Mn_3O_4$, 18 per cent). Moreover, fast Fe-Mn deposits ($Mn_3O_4$, 8 per cent), which resulted from soil cohesion effected by the lixiviate of the concretions, are found near the surface.

## PHOSPHORIC ACID OF ORGANIC ORIGIN

Not only does active weathering affect the K, Ca, and Mg supplies of tropical soils, but it also influences the readily available phosphate content.

Large amounts of Fe and Al that have been liberated by active weathering are present in tropical soils. In fact, the content of ferric and aluminum oxides soluble in 25 per cent HCl may amount to as much as 30 per cent. The Fe and Al occur partly in the crystalline form, as hydrargillite, haematite, and limonite, and partly in the amorphous state sometimes mixed with silicic and phosphoric acids. The result is that when readily available phosphate is determined by methods commonly used in temperate zones[4] the figures are generally too low or too high: too low because Fe and Al may interfere with solution of the readily available phosphate in the soil; too high because Fe- and Al-phosphates, which

TABLE 1

*Mineral content of "heavy" fraction of soil at various stages of weathering*

| STAGE OF SOIL WEATHERING | ORE + OPAQUE | HYPERSTHENE | AMPHIBOLE | ALLANITE | ZIRCON |
|---|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Rhyolitic tuff............ | 43 | 5 | 42 | 4 | 6 |
| Slightly weathered..... | 53 | 2 | 32 | 5 | 8 |
| Medium-weathered...... | 63 | 1 | 14 | 10 | 13 |
| Strongly weathered...... | 36 | tr. | 5 | 28 | 31 |
| Very strongly weathered............. | 20 | 0 | 0 | 40 | 40 |

may also be present in these soils and which are of little use to plants if the pH is low, also dissolve during the extraction. The common temperate-zone methods of analysis often reveal, for example, almost no readily available phosphate in the soil, or higher values for phosphate in the subsoil, where Fe- and Al-phosphates accumulate, than in the surface soil.

### *Determination of organic phosphate*[5]

*Organic and inorganic P.* A quantity of soil equivalent to 20 gm. on a moisture-free basis is placed in a 600-ml. beaker. About 100 ml. water and 10 ml.

[4] Sekera and Morgan methods of extraction with water containing $CO_2$ and with 2 per cent citric acid.

[5] Hudig, J. Modern grondonderzoek. *Landbouwk. Tijdschr.* 46: 354-364. 1934.

Hudig, J. Chemisch onderzoek van tropische gronden. *Landbouwk. Tijdschr.* 49: 378-401. 1937.

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Marel, H. W. van der. Onderzoek naar het voorkomen van organische fosforverbindingen in de grond. *Landbouwk. Tijdschr.* 47: 85. 1935.

10 per cent acetic acid are added, the latter to prevent the decomposition of hydrogen peroxide by manganese, which is commonly present in tropical soils. The solution is boiled, after which 40 ml. 30 per cent $H_2O_2$ (free from phosphoric acid) is added. After scumming has ceased, boiling is continued until all peroxide has disappeared. Drying on a water-bath follows and then extraction with 200 ml. HCl (sp. gr. 1.035, about 7 per cent) for 1 hour on a water-bath at 55° C. Next, 200 ml. water is added and the solution is filtered. In the filtrate, $P_2O_5$ is determined by either the gravimetric method according to Lorenz[6] or the colorimetric method according to Chapman[7]. The second method does not require elimination of silicic acid. In view of possible disturbances due to excess HCl, however, no more filtrate may be used than to a strength of 1 ml. HCl (sp. gr. 1.035).

*Inorganic phosphate* is determined as above, except that no peroxide is used.

*Organic phosphate* is determined by subtracting the inorganic from the total.

### Occurrence of organic phosphate

*Rhyolitic soils of the East Coast of Sumatra.* The rhyolitic soils of the East Coast of Sumatra contain but little phosphate because they originate from very "acid" rocks. Even in soils that are still only slightly weathered, extraction with 7 and 25 per cent HCl reveals not more than 0.006 per cent and 0.030 per cent $P_2O_5$. This corresponds to 180 and 900 kgm. $P_2O_5$ per hectare, to a depth of 30 cm. The results obtained by the methods of Sekera and Morgan also indicate a great deficiency of phosphate.

Experience shows, however, that on these slightly weathered rhyolitic soils P-deficiency symptoms appear only sporadically in the rubber, oil palm, tea, and sisal plantations. Likewise, various phosphate-containing fertilizers fail to increase yields, even after long years of growing crops with high phosphate requirements, such as sisal, which need as much as 80 kgm. $P_2O_5$ per hectare every year.

If, the amount of organic phosphate in these soils is determined, however, 0.040 to 0.050 per cent $P_2O_5$ is found, corresponding to 1,200 or 1,500 kgm. $P_2O_5$ per hectare to a depth of 30 cm.

Apparently in this humid, tropical climate enough P is available to plants from the organic material in the soil.

The organic P occurring in these slightly weathered soils was formed by the previous tropical forest and accumulated in the surface layer of the soil. This has been a very long process, for after legumes have been grown for many years on rhyolitic soils poor in P only a slight increase in organic P (0.001 per cent) is observed. A similar observation was made after a field was allowed to lie fallow for 10 years, which in tropical climates results in development of a thick plant growth.

After clearing a dense forest on the East Coast of Sumatra, one commonly

[6] von Lorenz. Methoden van Onderzoek van het R.L.P. te Maastricht, p. 16. 1932.

[7] Chapman, H. D. Studies on the blue colorimetric method for the determination of phosphorus. *Soil Sci.* 33: 125–134. 1932.

finds in the coarse-grained rhyolitic soils not more than 5 per cent humus, even when precautions have been taken to prevent erosion and fire.

The more the soil is cultivated, which means oxidation of the humus, and the more the surface soil, which contains most of the humus, and consequently also of the organic $P_2O_5$, is washed away, the more the humus content, and with it the organic P, drops. In strongly weathered soils and at places where the surface soil has been washed away, the amounts of humus, $P_2O_5$ soluble in 7 per cent HCl, and organic $P_2O_5$ are usually not higher than 0.8 per cent, 0.005 per cent, and 0.010 per cent, respectively.

The need for P in the soils at this stage varies, naturally, with crop requirements. Oil palms, for instance, take less $P_2O_5$ from the soil—only about 50 kgm. $P_2O_5$ per hectare a year in the form of harvested bunches—than does sisal.

*Tertiary soils of the East Coast of Sumatra.* The soils of the tertiary period on the East Coast of Sumatra and on Atjeh are derived mainly from sandstone and slate, rocks that already have undergone one or more weathering cycles. Consequently one would not expect to find much P in these soils. The main types, according to locality and color, found in this region are the red, high soils; the gray, low soils; and the white to gray-white, low soils.

In the red, high soils, the topsoil (0 to 30 cm.) usually contains not more than 1 per cent humus, 0.004 per cent $P_2O_5$ soluble in 7 per cent HCl, and 0.006 per cent organic $P_2O_5$, if no $FePO_4$ and $AlPO_4$ accumulations are present. The figures for inorganic $P_2O_5$ become much higher in the presence of such accumulations. Very little P, thus, is contained in the red soils. Even rubber, which in the drawn-off latex removes only about 15 kgm. $P_2O_5$ per hectare a year from the soil, responds markedly to applications of phosphate fertilizers.

Richer in P than the red, high soils, the gray, low soils contain as much as 2 or 3 per cent humus, about 0.007 per cent $P_2O_5$ soluble in 7 per cent HCl, and about 0.030 per cent organic $P_2O_5$. These high figures result from the alluvium left by the rivers. This is in reality washed-off topsoil containing P from elsewhere.

The white to gray-white, low soils contain mostly kaolin and coarse quartz, which is virtually devoid of P. Consequently, no substantial accumulations of P could occur in the former vegetative cover. Some organic P, however, circulated in these soils in the form of fallen leaves, which allowed somewhat thin forests to be developed. The kaolin-rich soils contain only about 0.003 per cent $P_2O_5$—the inorganic form soluble in 7 per cent HCl plus the organic form—which is equivalent to about 90 kgm. $P_2O_5$ per hectare, to a depth of 30 cm. Here phosphate fertilization greatly increases yields.

### Occurrence of inorganic phosphate

Although, in certain cases, phosphate of organic origin present in the humus may be very important to plant nutrition in tropical soils, it is not essential for optimum plant growth. This is evident in the andesitic ash soils of the Kloet volcano in Java. Here, soon after the land is cleared, its content of humus and of organic P is only 0.5 per cent and 0.004 per cent, respectively. This is due to active oxidation which takes place in these coarse well-drained soils under

the humid, warm climate. Symptoms of phosphorus deficiency, however, are not evident in the coffee, rubber, sugar cane, and sisal plantations even after long cultivation.

A single extraction with 7 per cent and 25 per cent HCl, however, dissolves 0.060 per cent and 0.100 per cent $P_2O_5$, respectively. These figures are equivalent to 1,800 and 3,000 kgm. $P_2O_5$ per hectare 30 cm. deep. Since these ash soils are still only very slightly weathered, $FePO_4$ and $AlPO_4$ are virtually absent from them, as shown by extraction with dilute NaOH (sp. gr. 1.040).

It follows, then, that the high P figures obtained by extracting these ash soils with HCl are almost entirely due to solution of minerals containing P, in this case, basic volcanic glass and apatite, inclusions in hypersthene and anorthite. These minerals, therefore, can satisfy completely the phosphate requirements of crops under tropical conditions.

## SUMMARY

The content of readily available plant nutrients in tropical soils cannot be determined by methods commonly used in temperate zones, because such methods fail to measure the plant nutrients set free from minerals by the active weathering that takes place in a hot moist tropical climate.

It was found, for example, that in the tropical lowlands, oligoclase, amphibole, and hypersthene could supply enough K, Ca, and Mg for most of the crops, such as sugar cane, oil palm, rice, coffee, and rubber, cultivated there. Furthermore, it was found that anorthite could supply sufficient Ca and K, and biotite enough Mg, for crops like sisal which need large amounts of these elements.

Mineralogical analysis, in combination with extraction of the soil with 25 per cent HCl, is recommended for determining the readily available plant food content of tropical soils.

As weathering progresses, the less readily decomposed minerals accumulate. It was found, for example, that in strongly weathered rhyolitic soils of Sumatra's East Coast, the heavy fraction consisted almost entirely of allanite and zircon.

Active weathering of tropical soils affects not only mineral elements but also the readily available phosphate, and methods of analysis that do not take into account organic phosphates in the soil are unsuited to tropical conditions.

It was found, for example, that phosphoric acid of organic origin which is present in the soil can supply enough of this nutrient to the principal crops—rubber, tea, oil palm, and sisal—to produce optimal harvests. The organic phosphate was accumulated by the former forests. Such phosphate soon disappears when land is cultivated.

Thus the organic phosphate content of just-cultivated slightly weathered rhyolitic soils of the East Coast of Sumatra fell from 0.05 per cent $P_2O_5$ to about 0.02 per cent under more prolonged cultivation. In similar soils that had been cultivated for 10 years, the figure was only about 0.01 per cent.

It was found, further, that under tropical conditions phosphoric acid derived from basic volcanic glass and from apatite inclusions of hypersthene and anorthite, amounting to about 0.10 per cent $P_2O_5$ soluble in 25 per cent HCl, can also deliver sufficient phosphoric acid for optimal harvests.

# SOIL ACTINOMYCETES OF BIKINI ATOLL WITH SPECIAL REFERENCE TO THEIR ANTAGONISTIC PROPERTIES[1]

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In connection with the atomic bomb experiments carried out at Bikini Atoll in July 1946, a large number of scientists were concentrated in that area obtaining information on natural phenomena never before gathered in those islands.

The geographical position of the islands of Bikini Atoll places them within the equatorial zone, centered at 11°35′ N. latitude 165°22′ E. longitude. Bikini is an oval-shaped atoll, about one third of the circumference of which is composed of islands. Rongelap, a similar atoll which lies to the east, was also studied. Both atolls form a part of the group known as the Northern Marshalls. They lie in the North Equatorial current, a westerly drift of water largely wind-driven by the northeast trade winds. The wind direction during the period of investigation averaged a steady east-northeast at a speed of 18 knots. The temperature year round varies only a degree or so from 82°F.

One of the phases of the marine biological program was that concerned with bacteriological experiments comprising biological oxygen demand and population studies which were conducted in Bikini lagoon and neighboring waters. The results of some of these studies were recently reported (1). In an effort to obtain microbiological information about the soil on these islands, population studies were conducted on a variety of soils taken from the islands of both Bikini and Rongelap Atolls.

This paper reports the microbiological studies of these tropical soils with particular reference to the actinomycetes, their antagonistic properties, and the production of an antibiotic substance by one of these organisms.

## GENERAL NATURE OF THE SOILS

The initial samples of soil were obtained from Bikini Island, adjacent to plant roots and from areas free of vegetation. Samples were taken from several depths of soil. The Bikini soil, and this holds for the islands in general, consists of almost pure calcium carbonate, known as "foraminiferal sand" composed of fragments of coral and tests of foraminifera. The annual rainfall is scanty, and the soils are exceedingly dry. This was true of the samples taken, even though the period was considered as the rainy season. The pH of the soils ranged from 8.7 to 9.2. The pH studies were made on fresh soil samples in the Bikini Area with

a Beckman pH meter. The organic content studies were conducted after the soil samples had been brought back to New Jersey. Determination of the loss on ignition gave rather erratic results, perhaps because of loss of hygroscopic water, of water of constitution, and of $CO_2$ from the $CaCO_3$ of most of these soils. However, a modification of the Schollenberger method of carbon determination (6) gave reproducible results. Some of the pH values for the Bikini soils were higher than those of other islands; others were lower, averaging around pH 8.0. In a soil under a tern rookery, which contained more than 10 per cent organic matter, the pH value was as low as 6.0. There were certain areas on the islands of both atolls beneath Tournefortia and Pisonia trees where leaf mold was nearly 12 inches deep. In some localities a considerable amount of bird manure made the soil rich in nitrogen. This was particularly true in locations under trees used as a rookery by the terns.

In soil areas where jungle litter accumulated, such as under large trees, very little evidence of decomposition was noted. The plant residues down to the sand showed dried, well-preserved plant parts. Occasionally there was evidence of limited decomposition of leaf molds. It is believed that such lack of decomposition of dead plant parts is due, in part, to the extremely dry environment with scanty rainfall during most of the year. The jungle litter showed little evidence that it supported the growth of fungi. The coarse foraminiferal and coral sand which lies beneath this jungle litter offers a very porous substratum which keeps the area well drained. The total numbers of microorganisms found in these soils further emphasize the small amount of decomposition going on, which in turn, allows organic nutrients to remain locked up in the surface litter. A large part of the soil surface on these islands was exposed to the sun and was free of dense plant growth. There were, however, areas of extensive vegetation including grasses and sedges. In some areas in the center of these islands the surface of the sand was covered with an algal mat and very little else.

The pH and organic matter determinations for two representative islands, Rongelap and Bikini, are presented in table 1. Soil samples were obtained and similar analyses made from most of the other islands on both atolls, but they differed only slightly from these shown here.

### GENERAL MICROBIOLOGICAL POPULATION OF THE SOILS

The soils were plated out on ordinary bacteriological media, such as meat extract peptone agar, a number of dilutions being used. Incubation was at 28°C. Many of the soil samples demonstrated an exceptionally high population of actinomycetes, frequently more than 95 per cent of all colonies appearing on the plates. The bacteria were found to be mostly spreaders. Various Aspergilli and Penicillia were the predominant forms of what few fungi were present. The spreader types of bacteria appeared largely in soils adjacent to plant roots.

The total numbers of microorganisms in the soils of Bikini ranged from 3,000 per gram in soil free of vegetation to 59,000 in soil adjacent to plant roots. This is the picture characteristic of Bikini Island and of numerous islands of Bikini Atoll as well as the islands of Rongelap Atoll. Data for both Bikini and Rongelap Islands appear in table 2.

The predominance of actinomycetes among the soil microorganisms is of particular significance, since ordinarily the abundance of these organisms is associated with well-fertilized fields soils, especially those rich in undecomposed

TABLE 1

*Organic matter content and reaction of soils studied*

| BIKINI ISLAND | | | RONGELAP ISLAND | | |
|---|---|---|---|---|---|
| Sample number* | Organic matter | pH | Sample number† | Organic matter | pH |
| | *per cent* | | | *per cent* | |
| 1 | 1.02 | 9.2 | 1 | 4.40 | 8.3 |
| 2 | 0.60 | 9.2 | 2 | 1.84 | 8.4 |
| 3 | 0.60 | 9.2 | 3 | 0.32 | 8.4 |
| 4 | 1.40 | 8.7 | 4 | 0.32 | 8.0 |
| 5 | 0.80 | 8.7 | 5 | 0.45 | 8.0 |
| 6 | 0.52 | 8.7 | | | |

* Bikini Island samples were obtained as follows: 1. Surface soil, Bikini, 100 yards from ocean. 2. Same location, 2 inches depth. 3. Same location, 6 inches depth. 4. Surface soil, adjacent to small shrub roots, 100 yards from ocean. 5. Same location, 2 inches depth. 6. Same location, 6 inches depth.

† Rongelap Island samples were obtained as follows: 1. Surface soil, low area, center of island. 2. Same location, 6 inches depth. 3. Same location, 12 inches depth. 4. Surface soil, 100 feet from ocean, no plant life. 5. Surface soil, same location, adjacent to grass roots.

TABLE 2

*Distribution of microorganisms in different soils from Bikini and Rongelap Islands as shown by the plate method*

Total numbers per gram of soil

| SAMPLE NUMBER* | BACTERIA | FUNGI | ACTINOMYCETES |
|---|---|---|---|
| Bikini | | | |
| 1 | 100 | 100 | 2,900 |
| 2 | 100 | | 4,700 |
| 3 | | 200 | 3,200 |
| 4 | 3,000 | 500 | 17,000 |
| 5 | 1,000 | | 58,000 |
| 6 | 1,000 | | 36,000 |
| Rongelap | | | |
| 1 | 160,000 | | 600,000 |
| 2 | 100,000 | | 800,000 |
| 3 | 3,000 | 1,000 | 10,000 |
| 4 | 1,000 | | 191,000 |
| 5 | | | 4,000,000 |

* Descriptions of soil samples are given in footnotes to table 1.

organic matter, although they have also been reported to occur abundantly in semiarid soils (9). Actinomycetes have been reported to be sensitive to an acid reaction, and appear to make a more extensive development than bacteria in soils of low moisture content (10). This may explain, in part at least, their

predominance in the soils of these islands.    Killian and Feher (5), in their studies of alkaline desert sands, reported that the predominating microorganisms present in such soils were spore-forming bacteria and actinomycetes.    Waksman and Curtis (8) examined two California soils which differed only in fertilization.    The soils contained large numbers of microorganisms, the unfertilized soil giving, however, a higher percentage (36.3 per cent) of actinomycetes than the fertilized soil (15 per cent).

### ANTAGONISTIC PROPERTIES OF ACTINOMYCETES

A number of actinomycete cultures were isolated from the plates and brought back to this country for further study.    They were tested by the usual agar streak procedure for their ability to produce substances with antibacterial

### TABLE 3
*Distribution of antagonistic properties among actinomycetes*

| ACTIVITY | ZONE OF INHIBITION | BACILLUS SUBTILIS | ESCHERICHIA COLI | MYCOBACTERIUM AVIUM | MYCOBACTERIUM PHLEI |
|---|---|---|---|---|---|
| | | | *Nutrient agar†* | | |
| | *mm.** | | | | |
| None | 0 | 30 | 78 | 30 | 26 |
| Weak | 1–9 | 3 | 13 | 29 | 16 |
| Medium | 10–19 | 46 | 3 | 35 | 35 |
| Strong | 20–35 | 21 | 6 | 6 | 23 |
| | | | *Dextrose asparagine agar†* | | |
| None | 0 | 22 | 80 | 57 | 14 |
| Weak | 1–9 | 35 | 14 | 8 | 10 |
| Medium | 10–19 | 28 | 6 | 35 | 70 |
| Strong | 20–35 | 15 | 0 | 0 | 6 |

* Agar streak method used.
† Numbers reported in per cent of total cultures.

activity.    In addition to the cultures of actinomycetes isolated from the fresh soil samples at Bikini, other cultures were isolated from the soil samples brought back from these islands to New Jersey.

The following test bacteria were used for obtaining the antibiotic spectrum: *Bacillus subtilis, Escherichia coli, Mycobacterium avium,* and *M. phlei.*    Two media were used, namely, nutrient or meat extract peptone agar and dextrose asparagine agar.    Table 3 presents a summary of some 250 actinomycete cultures selected at random from these soils and tested.

The results show that on nutrient agar, 78 per cent of the cultures had no activity against *E. coli,* 13 per cent had a limited or weak activity, and 3 and 6 per cent respectively had fair and strong activity.    On the other hand, the gram-positive bacteria, including the acid-fast mycobacteria, were much more sensitive to a greater proportion of the actinomycete cultures.    These results bear out pre-

vious observations from this laboratory (11) and from other laboratories (2) concerning the distribution of antagonistic properties among actinomycetes.

Of the cultures that showed the most marked activity against all four test organisms, a number were selected for further studies. These were grown in both static and submerged liquid culture media using nutrient broth and starch tryptone broth, the two media found to be most favorable to the production of streptomycin (7) and streptothricin (12) respectively. As a result of these studies, one organism in particular, an undescribed species of Streptomyces, grew readily on most of the media and produced an antibiotic substance in the culture filtrate. The antibiotic was very similar to, if not identical with, streptomycin and was, therefore, described tentatively as streptomycin II (3, 4). The organism which produces this form of streptomycin is quite different from *Streptomyces griseus*, the streptomycin-producing organism. It is very similar to *S. griseolus* (No. 96) Waksman, described many years ago from this laboratory, but differs in some respects and has, therefore, been named *S. bikiniensis* (3, 4).

## SUMMARY

In connection with the recent atomic bomb experiments at Bikini Atoll, the soils of various islands in that region were studied from a microbiological aspect.

These soils were arid, alkaline, and contained a comparatively low microbial population. Actinomycetes were by far the most abundant type, averaging in some instances 95 per cent of the population.

A number of these actinomycetes were isolated and brought back to this laboratory for further study. In this connection, the antagonistic properties of the actinomycetes were studied.

One actinomycete, an undescribed species, has been studied more extensively than the others, for it was found to produce, under certain conditions, an antibiotic which resembles streptomycin in many respects and which has been designated as "streptomycin II." The organism which produces this antibiotic is quite unlike the streptomycin-producing *Streptomyces griseus*, and will be known as *Streptomyces bikiniensis*.

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# MYCORRHIZAE AND THEIR RELATION TO FOREST SOILS[1]

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The absorptive organ of the terrestrial plant is normally considered to be the root hair associated with the actively growing root tip. That such is not the case for the large majority of trees, or for a great many other land plants, has been strikingly pointed out by Hatch (10). Under a wide range of soil conditions and for a wide range of species, the root hair may be partly or entirely replaced in function by a complex association of plant root and soil fungus. Such an association results in the formation of a morphologically distinct organ descriptively termed *mycorrhiza* by Frank in 1885. The term is a compound Greek word meaning literally, fungus-root.

Extensive reviews of the historical development of the subject are available (10, 23, 24). Although by no means the first botanist to observe associations of soil fungi with roots of higher plants, Frank systematically noted the regularity and prevalence of the mycorrhizal association and first regarded it as an instance of mutualistic symbiosis. The fungus-roots described by Frank were found to consist of a young root enclosed within a sheath of fungus mycelium. According to present nomenclature, this type of organ is an *ectotrophic mycorrhiza*, and the mycelial sheath is the *mantle*. The mantle is frequently so dense as to prevent any contact between the root tissue and the soil. Cross sections of this type of structure show fungal hyphae growing inward between the cortex cells, penetrating the middle lamella in a continuous network extending in many instances to the vascular tissues. This hyphal network, seen in transverse section, is known as the *Hartig net*. Ectotrophic mycorrhizae are usually found in plants the roots of which are differentiated into the anatomical types long roots and short roots (3).

A second general type of mycorrhizal structure is known as the *endotrophic mycorrhiza*. Here the mycelium of the fungus penetrates the cells of the primary root cortex, forming coils and swellings within the cells but appearing on the root surface as individual hyphae only. The mantle and the net, characteristic of ectotrophic structures, are absent, and the external appearance of this mycorrhiza is generally that of a normal root, possessing true root hairs in many instances. Any parasitism resulting from the invasion of the fungus comes to an end upon digestion of the branched and coiled systems by the individual root cell.

It is now generally recognized that very frequently there is no sharp distinction of the kind postulated by Frank between the ectotrophic and endotrophic types of structures. Some characteristics of both types may be combined with both intercellular and intracellular infection varying in intensity; such mycorrhizae are described as *ectendotrophic*.

Melin is cited (24) as describing in 1917 mycorrhizae which differ morphologically from the normal and are thought to be the expression of a one-sided parasitism to the benefit of the invading fungus. These structures Melin named *pseudomycorrhizae,* asserting that on soils having a high content of soluble salts or a reaction higher than pH 6.0 they may replace true mycorrhizae (39).

At least one other term should be mentioned in connection with the literature on mycorrhizae: that is *mycotrophy*. Stahl (36) in 1900 applied the term *mycotrophy* to the processes of plant nutrition by means of mycorrhizae, and it implies that the higher plant makes use of the products of fungal activity in its own food economy (24).

### ROOTS OF CONTROVERSY

No consideration of the subject can, at the present time, dismiss the elements of controversy which have long clouded discussions of the mycotrophic habit. According to the reviews previously cited, Frank saw in the mycorrhizal structure an organ of tremendous importance in the nutrition of plants. In a series of papers which have become classics in botanical literature, he put forth his views and was met by a storm of criticism. The early controversies stimulated observations and interest so that with the later recognition of the endotrophic type as even more widespread than the ectotrophic, it became apparent that mycotrophy was unquestionably normal and remarkably constant. Much of the early lack of agreement on mycorrhizae may be attributed to failure to discriminate between true mycorrhizae and pseudomycorrhizae (24) and to faulty concepts of the true nature and morphology of long roots and short roots (10). These reasons and others (10) help account for the vigor with which the newly formed school of pathology opposed the concept of mutual benefit arising from the higher plant-fungus association. This group conceived of the mycorrhizal fungi as purely pathogenic, invading the root at the expense of the tree (10, 23, 24, 39). Of this concept, Raynor and Neilson-Jones (24, p. 21) recently wrote:

How this interpretation can have been seriously maintained in view of the constancy and stability of the structural features and the patent fact that mycorrhizal activity and abundance of mycorrhizas are correlated invariably with healthy growth and maximum vigour of the host trees, unaccompanied by any symptoms of disease, is difficult to understand.

By 1904 the brilliant researches of Noel Bernard had conclusively proved the symbiotic value of certain endotrophic mycorrhizae (23). Introduction of pure-culture techniques established the importance of mycorrhizal fungi in the germination of orchids. As of 1935 Hatch (10) pointed out that, unlike the case of the orchid fungi, evidence with respect to ectotrophic mycorrhizae was largely circumstantial, and that there was still lacking incontrovertible proof that mycorrhizal fungi alone are responsible for the stimulated growth observed in infected seedlings. Hatch clearly recognized that the use of pure cultures of mycorrhizal fungi for inoculating seedbeds would alone provide the evidence sought.

Such proof was provided in 1936 by Hatch (9) in America and by Young (40) in Australia. Both of these workers introduced pure cultures of mycorrhizal

fungi into seedbeds lacking these microorganisms, and both obtained proof beyond reasonable doubt of the beneficial nature of the mycorrhizae equipment. The study of Hatch (9) involved quantitative chemical analyses of the plants and demonstrated that mycorrhizal pine seedlings absorbed 86 per cent more nitrogen, 75 per cent more potassium, and 234 per cent more phosphorus than non-mycorrhizal plants in the same substrate. Other quantitative studies have yielded similar results (7, 21). As the result of these pure-culture studies and quantitative investigations, there now appears to be general acceptance of the beneficial nature of ectotrophic mycorrhizae. It is not to be concluded from this that the atmosphere of controversy is abandoned, for, although occasional repercussions of the old pathogenic theory appear [(5), for example], present-day disagreements among the workers stem largely from attempts to explain the mechanisms of the association.

## THE HIGHER-PLANT COMPONENT

It has already been mentioned that early doubts as to the normal and wide-spread occurrence of mycorrhizae were soon dispelled by a wealth of observational data. Rayner and Neilson-Jones (24) recently asserted that more than 80 per cent of all flowering plants, including a great majority of both temperate and tropical crop plants, are mycorrhizal in nature. In the plant kingdom as a whole, the endotrophic (including ectendotrophic) mycorrhizae are found much more frequently than the ectotrophic (3, 10, 14, 24).

Organs of the ectotrophic type are most common among forest trees and are found in all genera of the *Pinaceae, Fagaaceae, Betulaceae, Salicaceae*, in *Carya* and several woody genera of other families, and in a few herbs (3, 10, 14, 39). Among forest trees the endotrophic habit is by no means unusual and is found in the genera *Fraxinus, Populus, Juglans* and in a number of coniferous species (24).

With respect to horticultural species, the findings of Schuster *et al.* (34) are probably indicative. Ectotrophic mycorrhizae on filberts and endotrophic mycorrhizae on walnuts were so generally found that few noninfected roots could be noted. Domink and Jagodzinski (6) recently examined 19 species of fruit trees and shrubs and found all of them producing mycorrhizae.

Fungus-roots in crop plants have in recent years received considerable attention from workers in the British Empire. Mollison (30) found a phycomycete fungus forming such associations in nearly all clover plants obtained from widely scattered localities in Great Britain. She also found mycotrophy in wheat plants, although in that case the occurrence seemed to be more seasonal. Sabet (32) mentioned the occurrence of mycorrhizae in cotton from Egypt. Levisohn (12, p. 82) found widespread mycorrhizal infection among rice plants collected from India. Nor are many common garden plants without mycorrhizae (22).

## THE FUNGAL COMPONENT

The fungi concerned in the ectotrophic type of mycorrhizal structure are now rather well identified. In association with forest trees, the majority of the

fungal symbionts are members of the *Basidiomycete* class, and chiefly of the *Hymenomycetes* within that class. The common genera are *Boletus*, *Amanita*, *Tricholoma*, *Boletinus*, *Lactarius*, *Cortinarius*, and *Russula* (10, 24, 39). Certain mycorrhizae-formers, as *Amanita*, may be found associated with a wide variety of tree species, whereas others, as *Boletus*, are relatively specific (39). Romell indicated (27) that the relationship is often highly specific in nature, and he later obtained evidence that there are facultative tree mycorrhizal fungi as well (28). At least one species of the *Gastromycetes* has been experimentally proved a mycorrhiza-former of trees, and it is thought not unlikely that species of *Tuber* and related *Ascomycetes* may be included in the list (25).

For the endotrophic type of mycorrhizal structure the taxonomy of the fungal partners is still largely uncertain (24). They are considered generally to be part of the large interrelated group of *Phycomycetes*, or of the genus *Rhizoctonia* of the Fungi Imperfecti (3).

### INCIDENCE OF THE ASSOCIATION

Although Wilde (38) expressed his conviction that 99 per cent of all practicing foresters will not have to lose any sleep over the problem of mycorrhizal inoculation, there are many other reports (10, 24) which indicate a delicate adjustment of the mycorrhizae with its environment. Under certain conditions at least, inoculation of plants by mycorrhizae-forming fungi is not a foregone conclusion, and the influence of soil factors may be of consequence.

One of the possible reasons that immediately comes to mind for the failure of mycorrhizae to develop where otherwise expected, is the absence of the fungal component from the soil. Reports of forest nursery and plantation failures in many parts of the world (9), and their subsequent response to inoculation with mycorrhizal fungi, bear out the possibility that certain soils may lack the proper fungi. Hatch (9) and McComb (15) were among those demonstrating the difficulty of obtaining satisfactory tree seedling growth on prairie soils unless artificially inoculated with suitable fungi. White (37) illuminated the whole problem of treeless areas of the prairies when he found that the lack of beneficial action of mycorrhizal fungi appears to be the major condition inhibiting the growth of trees on mycorrhiza-free prairie soils.

As Rayner (25) pointed out: "The production of fungus-roots by a tree seedling growing under natural conditions is not a mere matter of propinquity: both young root and mycelium must be in a physiological state favorable to mutual interaction, this in turn being determined by conditions existing in the natural environment of the roots." Many investigators have searched the natural environment of roots for an insight into the character of the fungus-root relationship.

The literature has frequently attested to the concentration of mycorrhizae in soils rich in humus, and this relationship has been prominent in several theories proposed to establish conditions essential to mycorrhizal development (10). For forest trees Romell (26) voiced the common experience that mycorrhizae are most abundant in the raw humus types, whereas in a typical mull soil, mycotrophy

occurs to a much lesser extent. Under raw-humus conditions Melin (19) found these associations better developed in the F humus layer than in the H, and obtained evidence that the conditions for mycorrhizal formation may vary with different humus types.

Some early work on pure cultures indicated that the hydrogen-ion concentration of the soil may play a part in determining mycorrhizal distribution. Lohman (13), however, found that although best developed and most common in soils with a pH below 6.5, mycorrhizal fungi were present in neutral and alkaline soils. Björkman (2) found that the degree of acidity varying from pH 4.5 to 7.5 in the soils studied seemed in no way to have affected mycorrhizal development.

Stahl (36) proposed in 1900 that frequency of occurrence of mycorrhizae was inversely proportional to soil fertility. In summarizing extensive experimental work which confirmed this theory for pines, Hatch (10) decided that in fertile soils characterized by luxuriant supplies of dissolved minerals, long-root tips rather than mycorrhizae serve as the chief organ of absorption. On the infertile soils typically encountered in forestry, however, mycorrhizal short-roots become numerous and well developed.

A number of other soil factors are known to be related to the failure of mycorrhizae to form under certain conditions. Among these factors are poor soil aeration and extremes in soil temperature and moisture (3, 39). In experiments with pine and spruce seedlings Björkman (2) found that light in relation to the supply of available nitrogen was a determining factor in the formation of mycorrhizae. The mycorrhizal development was in all soils poor at very low percentages of the total incident radiation in the open, and was, at the same radiation intensity, depressed at high nitrate contents.

The concept of mycorrhizae existing in a delicate state of balance with the soil environment has directed attention to the possibility that toxic substances present in the soil may adversely affect the association. Rayner and Nielsen-Jones (24) investigated this possibility in connection with plantation failures of exotic pines on heath soils, after inoculation of the soil with suitable fungi failed to yield mycorrhizae. Experimental evidence was obtained to substantiate the assertion that toxic substances of biologic origin were present. Investigation of the possible nature of this particular toxicity has touched upon the field of antibiotics. Brian et al. (4) were able to show that at least a part of the toxicity may have been due to production of fungistatic organic substances (possibly gliotoxin) by the *Penicillium* sp. dominating the microflora of those heath soils. Melin (20) reported that single-species leaf litter of Swedish forests exhibited antifungal properties toward many soil fungi. Cold-water extracts of the litter of maple, birch, beech, oak, aspen, and pine were shown to have a more pronounced growth-inhibitory effect on mycorrhizal fungi than on other *Hymenomycetes* inhabiting the litter.

Wilde (38) criticized the toxicity theory as set forth by Rayner and Nielson-Jones on both theoretical and experimental grounds. He expressed doubt that toxic substances are of any importance in mycorrhizal initiation, and pointed to recent work on prairie soils as proof that nonforest soils can be successfully

inoculated with pure cultures of mycorrhiza-formers without any preliminary detoxination of the soil. Heiberg (11) treated this toxicity theory more kindly and considered that ". . . the authors gradually approach the biological attitude toward forest soils which has been championed by P. E. Müller and his followers but is not yet generally accepted." Harley (8) also appeared willing to stress the importance of biological soil factors. He saw the relationship not only as a main association of two organisms, but also as a population of organisms living within the sphere of influence and themselves influencing the two main protagonists.

<div align="center">THEORIES OF SYMBIOTIC MECHANISMS</div>

Although there is no longer much question as to the dependence of many plants upon fungal symbionts forming mycorrhizae, there is considerable disagreement in interpreting the evidence regarding the mechanisms whereby exchange of nutrients takes place.

There are distinct differences between forest soils and agricultural soils with respect to nitrogen mobilization. The differences are particularly marked where the forest soil is of the raw-humus type; here available nitrogen is rarely found and the competition for that which results from decomposition of plant residues is intense. Combining these facts with the consistent occurrence of tree mycorrhizae in humus soils, Frank early propounded the organic nitrogen theory concerned with picturing mycorrhizae as the mechanisms for making available the nitrogen concentrated in humus. Hatch (10) critically examined the experimental evidence submitted for the organic nitrogen theory, especially with respect to the intensive researches of Melin during the period 1917–1927. He cited recent investigations which failed to confirm this theory under conditions in which the factor of nitrogen availability was strictly regulated. Hatch concluded that the nitrogen theory is untenable as a full explanation of the mycorrhizal habit. In the early literature frequent mention is found of the possibility that the fungi of the mycorrhizae act as fixers of atmospheric nitrogen in a manner analogous to that of the nodule bacteria of legumes. Allison et al. (1) examined this theory in 1934 and concluded that most assertions that mycorrhizal fungi can fix free nitrogen do not stand up under experimentation. There is evidence that a few species of *Phoma*, however, may be capable of this fixation (1).

Stahl (36) attempted to resolve some of the early conflicting observations on abundance and distribution of mycorrhizae by advancing his mineral salt theory of the basis for mycotrophy. He saw the mycorrhizal equipment of plants as organs which facilitate the absorption of mineral nutrients: under conditions of low soil fertility and high humus content the mycorrhizal plant is capable of competing with soil microflora for the limited supply of mineral salts. After a lapse of many years, this theory recently received much attention from several workers who placed it on a much firmer base with respect to experimental support. Hatch (10), after exhaustive research involving pure-culture methods, proposed a new explanation of ectotrophic mycorrhizae based upon the mineral salt hypothesis of Stahl. He considered that (a) ectotrophic mycorrhizae are

far more efficient than nonmycorrhizal roots in absorbing all nutrient elements ordinarily absorbed by roots; (b) this efficiency is due largely to the greatly increased surface area and the tremendous surface/volume ratios which characterize the fungal hyphae; (c) trees are dependent on symbiotic association with mycorrhizal fungi for their soil nutrients and, therefore, for their existence in all but the most fertile agricultural soils. Careful experiments by Mitchell, Finn, and Rosendahl (21) yielded results which they found agreed in every respect with the Stahlian-Hatch theory. Rosendahl (29) later demonstrated that mycorrhizae actually increased the intake of potassium from a sand-orthoclase medium for red pine. In view of such researches, Wilde (39) considered the possibility of utilizing the less soluble sources of potash and phosphates as not only a cheaper but a safer means of maintaining fertility in nurseries and arboricultural plantations.

Routien and Dawson (31) demonstrated that the presence of mycorrhizae enabled short-leaf pine roots to absorb calcium, iron, potassium, magnesium, and phosphorus at lower levels of base saturation of the clay substrate than was possible in their absence. The suggestion was made that increased $CO_2$ evolution results in greater production of carbonic acid, which in turn serves, in part at least, as a source of exchangeable hydrogen ions. Heightened metabolism of mycorrhizae-equipped seedlings was also considered by McComb and Griffith (16) to be associated with increased phosphorus uptake.

It is likely that views on the significance of mycotrophy should be modified to include effects on the carbohydrate nutrition of the tree as well as on the nitrogen and inorganic salt nutrition. The interpretations of Romell (27, 28) and Björkman (2) conceived of the mycorrhizal fungi parasitizing the roots of their hosts for readily utilizable carbohydrates; provided thus with energy requirements, these fungi are in favorable position to enter the competition for available nutrients. Björkman's recent views have been reported (35) thus:

... fungi enter the plants in the roots but do not develop unless for some reason the carbon-nitrogen ratio becomes wide. Increase in light, moderate nitrogen starvation, or strangulation causes an excess of carbohydrate. The mycorrhiza seems to remove this excess, and so benefit the plant. It acts as a parasite but only as long as the carbohydrate is in excess, thus actually benefiting the plant by removing the excess, but never as a parasite by removing the carbohydrate when it is not in excess.

MacDougal and Dufrenoy (17), however, showed a leaning toward the opposite view that mycorrhizal fungi may make carbohydrate available to the host plant. They cultured isolated segments of mycorrhizal pine roots and found them capable of independent growth for 28 months during which time the fungal partner synthesized carbohydrates adequate for growth for more than 2 years.

There is evidence at present that growth-promoting substances of a vitamin-like nature and plant hormones may be intimately concerned in nutritional conditions operative in the mycorrhizal association. Reviews of the work of Melin from 1925 on (10, 24, 33) recall that he found it no easy task to grow pure cultures of fungi isolated from mycorrhizae. Special cultural conditions were frequently

proved necessary. By 1940 Melin and his co-workers had clearly established the fact that certain species of fungi forming mycorrhizal structures are incapable of manufacturing their own supply of vitaminlike growth factors, and an external supply of these substances must be provided.

The theory that interchange of growth-promoting substances rather than of ordinary nutrients is the most important activity in the mycorrhizal relationship of trees was related by Romell (28). He drew attention to the luxuriant growth of mycorrhizae-free seedlings under certain conditions as evidence that such stimulation is unnecessary. That the root provides these growth factors needed by some fungal symbionts was suggested by Hatch (10). Work at the University of Wisconsin indicated that in artificial culture at least, such fungi are dependent upon the root component for thiamin and other vitamins (39). Root cells need not be the only external supply of growth substances, for Melin (20) found that extracts of forest litter exerted a growth-promoting effect of 150 to 300 per cent upon many known mycorrhiza-formers. Other microorganisms of the soil might logically provide an additional source of growth factors.

Not all mycorrhizal fungi require an auxiliary supply of growth factors (28, 33). Many species manufacture their own supply and, rather than receive these organic substances from the root, may indeed supply the root with them. The work (17) with prolonged culture of isolated mycorrhizae yields the picture of the fungal component mobilizing and translocating the main components of the protoplasm, including certain organic growth factors, to the root cells. Schopfer (33) reviewed the literature on the endotrophic mycorrhizae of orchids and vitamin growth factors. He concluded that orchid seeds exhibit a normal physiological avitaminosis, which is met by the contribution of the vitamin-synthesizing fungus existing symbiotically with the orchid plant.

In 1944 MacDougal and Dufrenoy (18) made a study of three extremes in mycorrhizal expression: a chlorophylless orchid with no roots, a terrestrial orchid with green leaves, and a pine tree. All three had highly developed mycorrhizal features. The chain of metabolic processes and the compounds translocated from the fungus to the higher plants were found to be identical. This is in hopeful contrast to the mass of reports available, most of which fall within the analysis of Rayner (24):

A traditional atmosphere of controversy envelops attempts to unravel the tangled skein of mycorrhizal relationships. The habit is so widespread among vascular plants, and its expression in different groups so varied that contributions to the elucidation of the problem as a whole are necessarily fragmentary.

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# HEAVY MINERALS IN SOME PODZOL SOIL PROFILES
## IN MICHIGAN[1]

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Observations made on soil profiles during a land-type survey in Charlevoix and Presque Isle Counties of Michigan suggested that certain morphological peculiarities in some of the podzol profiles might be explained through use of recent techniques in the study of heavy minerals. Furthermore, it was thought that such a study would aid in revealing geological differences in soil horizons and in determining the intensity of the weathering processes in various horizons. This paper reports an investigation conducted along these lines.

Investigations of heavy minerals in podzols have not been very extensive. Cady (2) differentiated the mineralogical characteristics of podzols from those of brown podzolic soils. Heavy minerals were decidedly less prevalent in the A horizon of podzols than in the C horizon. The minerals hornblende and hypersthene weathered rapidly, whereas magnetite and garnet were little affected. In the A and C horizons of brown podozolic profiles, the heavy minerals were found in similar quantities. Richard and Chandler (11) investigated three strongly developed podzol profiles from Quebec Province, Canada, and found that hornblende weathered rapidly in the $A_2$ horizon, whereas it was only slightly weathered in the C horizon. Hypersthene showed a somewhat similar reaction to weathering. Jeffries and White (9) showed that in Leetonia sand (podzol) zircon and anatase were abundant and typical; tourmaline, rutile, muscovite, chlorite, epidote, barite, magnetite, and leucoxene were present but not in sufficient quantities to be typical.

### SOILS STUDIED AND METHOD OF SAMPLING

Two groups of podzol soils were investigated; namely, Emmet, Kalkaska, and Wallace sands, which were designated as group I; and Grayling, Rubicon, Roselawn, and Eastport sands, designated as group II. Members of group I were characterized by a stronger expression of the morphological features of typical podzol profiles than were members of group II. Kalkaska and Emmet sands supported a forest cover of hardwoods, whereas the other types supported a pine cover.

Soil profile samples were collected under as near virgin forest conditions as

possible.  A large L-shaped pit was dug for each of the profiles, and each horizon was sampled along both arms of the "L" to take into account horizontal variations.  Large samples, approximating 50 pounds, were taken of each horizon.

### PRELIMINARY STUDIES

Preliminary studies included mechanical analyses and a determination of reaction, free alumina, iron oxide, and colloidal silica.  The pH of the soil was determined in the laboratory with the glass electrode using a 1:1 soil-water ratio. Organic matter, free alumina, iron oxide, and colloidal silica were removed as outlined by Truog *et al.* (14).   Free alumina, iron oxide, and colloidal silica were determined by the methods of Robinson (12) and Truog *et al.* (14).   Results of the chemical analyses, shown in table 1, indicate that there was a greater coating of free iron oxide around the particles in the group I soils than in those of group

TABLE 1

*Content of free alumina, iron oxide, and colloidal silica in B horizons of some Michigan podzol soils*

| SOIL | ORGANIC-FREE SOIL | | |
| --- | --- | --- | --- |
| | Alumina | Iron Oxide | Colloidal Silica |
| | *per cent* | *per cent* | *per cent* |
| *Group I* | | | |
| Wallace sand.................. | 0.72 | 0.32 | 0.10 |
| Kalkaska sand............... | 0.30 | 0.33 | 0.04 |
| Emmet sand................. | 0.07 | 0.31 | 0.15 |
| *Group II* | | | |
| Rubicon sand................. | 0.68 | 0.25 | 0.20 |
| Roselawn sand............... | 0.36 | 0.30 | 0.12 |
| Grayling sand................ | 0.57 | 0.30 | 0.11 |
| Eastport sand................ | 0.09 | 0.10 | 0.03 |

II.   The mechanical analyses, pH, and organic matter content of the soils are given in table 2.   With the exception of the organic matter in the A and B horizons, these soils consist chiefly of sand.

### HEAVY-MINERAL STUDIES

Heavy-mineral separations were made on the fine sands (0.25–0.02 mm.). The heavy liquid used for the separation was a mixture of tetrabromoethane and nitrobenzene having a specific gravity of 2.94.   One- to 2-gm. samples of fine sand (0.25–0.02 mm.) were placed in small centrifuge tubes containing the liquid mixture.   These were centrifuged at approximately 750 r.p.m. for about one hour.   The light minerals were decanted and the heavy minerals washed into a beaker with acetone, dried at 70° C., and weighed.

The percentage of total heavy minerals in oven-dry, organic-free soil is given in figure 1.   The results show that there were significantly greater amounts of heavy minerals in all horizons of the group I (Kalkaska, Emmet, and Wallace)

soils than in the corresponding horizons of the group II (Grayling, Rubicon, Roselawn, and Eastport) soils. In all the soils, the total amount of heavy minerals was greatest in the C Horizon. In most of the soils, the B horizon had the lowest content of heavy minerals.

After the total heavy minerals were weighed, they were spread on a gelatinized slide. The method of preparing the slide was similar to that described by Fair-

TABLE 2

*Mechanical analyses, content of organic matter, and pH of some Michigan podzol soils*

| SOIL TYPE AND HORIZON | ORGANIC MATTER | SEPARATES INORGANIC-FREE SOIL | | | pH |
|---|---|---|---|---|---|
| | | Sand (2.0-0.02 mm.) | Silt (0.02-0.002mm.) | Clay (< 0.0002 mm.) | |
| *Group I* | | | | | |
| Wallace sand  A | 2.0 | 96.2 | 2.3 | 1.0 | 6.5 |
| B | 0.8 | 96.4 | 0.6 | 0.9 | 5.5 |
| C | ... | 98.4 | 0.8 | ... | 6.5 |
| Kalkaska sand A | 2.8 | 96.5 | 1.7 | 1.4 | 6.0 |
| B | 0.8 | 94.9 | 2.3 | 1.0 | 4.8 |
| C | ... | 98.1 | 1.4 | ... | 6.0 |
| Emmet sand  A | 2.5 | 95.7 | 2.0 | 1.2 | 6.3 |
| B | 0.4 | 96.0 | 1.7 | 1.0 | 6.2 |
| C | ... | 98.3 | 1.2 | ... | 8.0 |
| *Group II* | | | | | |
| Rubicon sand  A | 1.7 | 98.4 | 1.0 | 0.6 | 7.0 |
| B | 0.1 | 97.1 | 0.5 | 0.1 | 6.0 |
| C | ... | 100.1 | 0.5 | ... | 7.0 |
| Roselawn sand A | 1.8 | 98.1 | 1.1 | 0.7 | 6.6 |
| B | 0.1 | 97.1 | 0.7 | 0.5 | 5.7 |
| C | ... | 99.7 | 0.6 | ... | 6.6 |
| Grayling sand  A | 1.9 | 98.5 | 1.0 | 0.7 | 6.3 |
| B | 0.2 | 97.5 | 0.6 | 0.7 | 5.3 |
| C | ... | 99.7 | 0.6 | ... | 6.3 |
| Eastport sand  A | 1.1 | 99.6 | 0.9 | 0.1 | 6.2 |
| B | 0.1 | 99.4 | 0.3 | ... | 6.8 |
| C | ... | 100.1 | 0.3 | ... | 6.4 |

bairn (4) and Marshall and Jeffries (10). The use of the gelatin-coated slides permitted the changing of immersion liquids without losing the grain. Identification of all the heavy minerals was primarily limited to determining the approximate refractive index, pleochroism, birefringence, extinction angle, color, and shape. Identification of the opaque minerals was facilitated by a magnetic separation.
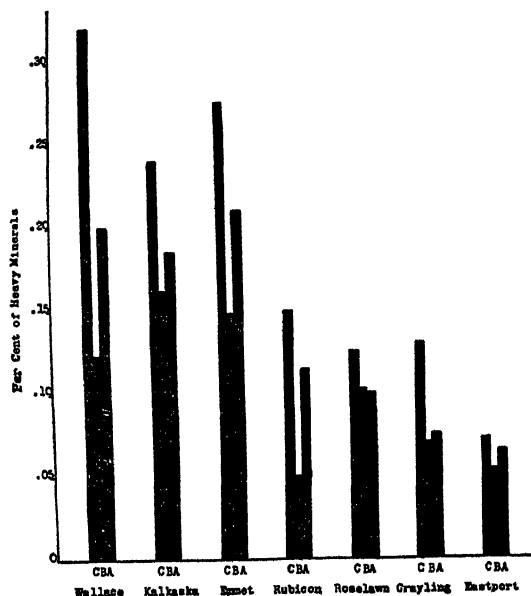
FIG. 1. PERCENTAGE OF HEAVY MINERALS IN FINE SAND FRACTION OF SOILS OF GROUP I
AND II

In 20 gm. organic-free soil

A grid micrometer ocular was used to measure the size of the grain within the fine sand fraction (0.25–0.02 mm.). The maximum cross-sectional area of each grain was determined as follows:



The hornblende particle is illustrated in black. The three grid squares are shown below the letters A, B, and C. To obtain the maximum cross-sectional area of the hornblende particle the grid squares that equal the hornblende particle size are counted. In the figure shown the maximum cross-sectional area is 3.

Mineral-count data are usually converted to weight percentages (2, 5, 8). The conversion is correct if the grains within the fraction have the same average volume and the same specific gravity. Coated unknown grains as well as different mineral shapes would reduce the accuracy of the conversion. In these studies the coated unknown grains were few in number. The shapes of the same species of minerals varied tremendously in some of the C and A horizons. It would seem, therefore, that the conversion of mineral counts of such varying dimensions to average volumes or weight percentages without correction would result in great errors. Mineral counts were not converted to volume or weight percentages, since observations showed that the shapes of the minerals and the

frequency of the maximum cross-sectional areas varied within and between horizons.

To show that the frequency distribution of the maximum cross-sectional areas is not the same, the data in table 3 are presented. These results show that in the A horizon the mode is near the 1.0 maximum cross-sectional area; in the B horizon, between the 0.5 and 1.0; and in the C horizon, between 1.0 and 20.

Hornblende, garnet, epidote, zircon, tourmaline, tremolite, muscovite, and the opaque minerals were identified.

TABLE 3

*Heavy-mineral count of dark green hornblende in Wallace sand*

| HORIZON | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---------|------|------|------|------|------|------|------|------|
| | Maximum cross-section area* | | | | | | | |
| | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| A | ... | 96 | 524 | 72 | 34 | 28 | 4 | 2 |
| B | ... | 474 | 496 | 88 | 38 | 32 | 8 | 4 |
| C | ... | ... | 1216 | 608 | 246 | 19 | 10 | 13 |

* The maximum cross-sectional areas are designated by the class marks 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 10.0 and by the class numbers 1, 2, 3, 4, 5, 6, 7, and 8. These class marks and class numbers correspond to the following maximum cross-sectional areas:

| CLASS NUMBER | CLASS MARK | MAXIMUM CROSS-SECTIONAL AREA (MM.) |
|--------------|------------|-------------------------------------|
| 1 | 0.25 | $(.075)^2/4$ |
| 2 | 0.5 | $(.075)^2/2$ |
| 3 | 1.0 | $(.075)^2$ |
| 4 | 2.0 | $2(.075)^2$ |
| 5 | 3.0 | $3(.075)^2$ |
| 6 | 4.0 | $4(.075)^2$ |
| 7 | 6.0 | $6(.075)^2$ |
| 8 | 10.0 | $10(.075)^2$ |

*Dark green and gray-green hornblende*

The hornblendes were the most numerous heavy minerals. The mineral counts are given in tables 4 and 5. The A and C horizons of group I soils, in general, contained much greater quantities than the group II soils. Eastport sand, because it probably contained recent wind-blown material, did not follow the pattern of the A horizon of group II soils. It contained a very high percentage of small grains, many more than could have weathered from the C horizon. The A horizons of Kalkaska and Emmet sands (soils that support a hardwood cover) showed a greater count and amount of dark green hornblende than Wallace, Rubicon, Roselawn, and Grayling sands (soils that support a pine cover).

Photomicrographs of hornblende (figs. 2 and 3) show a greater severity of

TABLE 4

*Heavy-mineral count of dark green hornblende, gray-green hornblende, and epidote in group I soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
|---|---|---|---|---|---|---|---|---|---|
| *Wallace sand* | | | | | | | | | |
| Dark green hornblende | A | .... | 96 | 524 | 72 | 34 | 28 | 4 | 2 |
| | B | .... | 474 | 496 | 88 | 38 | 32 | 8 | 4 |
| | C | .... | .... | 1216 | 608 | 246 | 19 | 10 | 13 |
| Gray-green hornblende | A | .... | 4 | 150 | 12 | 18 | 12 | 10 | 2 |
| | B | .... | 230 | 252 | 114 | 60 | 66 | 30 | 4 |
| | C | .... | .... | 77 | 10 | 32 | 16 | 16 | 6 |
| Epidote | A | .... | 4 | 318 | 30 | 10 | 4 | ... | ... |
| | B | .... | 22 | 18 | 18 | 8 | 2 | 2 | ... |
| | C | .... | .... | 400 | 176 | 35 | 16 | ... | ... |
| *Kalkaska sand* | | | | | | | | | |
| Dark green hornblende | A | 185 | 1684 | 120 | 50 | 24 | 17 | 19 | 19 |
| | B | ... | 56 | 264 | 208 | 160 | 64 | 58 | 28 |
| | C | ... | 96 | 1138 | 1238 | 86 | 202 | 53 | 31 |
| Gray-green hornblende | A | 1018 | 2405 | 26 | 20 | 19 | ... | ... | 15 |
| | B | ... | 32 | 464 | 102 | 66 | 42 | 12 | 18 |
| | C | ... | 12 | 298 | 120 | 34 | 14 | 5 | 19 |
| Epidote | A | ... | 37 | 13 | 15 | 19 | 11 | 6 | 6 |
| | B | ... | 2 | 28 | 36 | 28 | 10 | 6 | 2 |
| | C | ... | 5 | 43 | 17 | 14 | 14 | 5 | 2 |
| *Emmet sand* | | | | | | | | | |
| Dark green hornblende | A | .... | 65 | 1166 | 935 | 63 | 179 | 197 | 21 |
| | B | .... | 68 | 198 | 136 | 56 | 32 | 26 | 10 |
| | | .... | .... | 83 | 138 | 33 | 396 | 536 | 193 |
| Gray-green hornblende | A | .... | 53 | 1109 | 113 | 4 | 53 | 29 | ... |
| | B | .... | 46 | 300 | 178 | 192 | 106 | 24 | 10 |
| | C | .... | .... | .... | 110 | 110 | 28 | 17 | 19 |
| Epidote | A | .... | 4 | 65 | 69 | 2 | 27 | 11 | ... |
| | B | .... | .... | 10 | 20 | 16 | 10 | ... | ... |
| | C | .... | .... | .... | 3 | 3 | 28 | 17 | 6 |

weathering in the A horizons of Kalkaska and Emmet sands than in Rubicon, Roselawn, Grayling, and Eastport sands.

To represent the relative degree of weathering between group I and group II soils, one soil from each group was chosen. With the grain-size distribution of

TABLE 5

*Heavy-mineral count of dark green hornblende, gray-green hornblende, and epidote in group II soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1 0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Rubicon sand* | | | | | | | | | |
| Dark green hornblende | A | ... | 455 | 141 | 131 | 15 | 29 | 14 | 5 |
| | B | ... | 152 | 22 | 14 | 20 | 28 | 32 | 20 |
| | C | ... | 5 | 59 | 105 | 5 | 161 | 140 | 23 |
| Gray-green hornblende | A | ... | 281 | 37 | 16 | 4 | 7 | 2 | .. |
| | B | ... | 330 | 16 | 10 | 12 | 10 | ... | 8 |
| | C | ... | 11 | 59 | 36 | 5 | 57 | 11 | 11 |
| Epidote | A | ... | 122 | 151 | 23 | 6 | 7 | ... | .. |
| | B | ... | .... | ... | ... | ... | ... | 4 | .. |
| | C | ... | .... | 11 | 21 | 6 | 26 | 27 | .. |
| *Roselawn sand* | | | | | | | | | |
| Dark green hornblende | A | ... | 20 | 119 | 292 | 22 | 52 | 15 | 2 |
| | B | ... | 200 | 102 | 110 | 46 | 96 | 12 | 6 |
| | C | ... | .... | 200 | 269 | 40 | 90 | 20 | .. |
| Gray-green hornblende | A | ... | 7 | 53 | 26 | 4 | 2 | 2 | 1 |
| | B | ... | 240 | 46 | 78 | 130 | 100 | 6 | .. |
| | C | ... | 25 | 64 | 3 | ... | 1 | 13 | 6 |
| Epidote | A | ... | 4 | 51 | 30 | 4 | 9 | 5 | 5 |
| | B | ... | .... | 2 | 12 | 10 | 8 | 4 | .. |
| | C | ... | 3 | 25 | 38 | 4 | 1 | 3 | 9 |
| *Grayling sand* | | | | | | | | | |
| Dark green hornblende | A | ... | 68 | 230 | 95 | 10 | 30 | 8 | 15 |
| | B | ... | 14 | 314 | 100 | 16 | 18 | 56 | 3 |
| | C | ... | 3 | 3 | 34 | 18 | 107 | 88 | 26 |
| Gray-green hornblende | A | ... | 10 | 32 | 80 | 9 | 7 | 8 | 3 |
| | B | ... | 8 | 48 | 34 | 30 | 60 | 10 | 14 |
| | C | ... | .... | 8 | 16 | 3 | 47 | 23 | 4 |
| Epidote | A | ... | .... | 115 | 59 | 20 | 11 | 7 | 4 |
| | B | ... | .... | ... | ... | 6 | 4 | 2 | 2 |
| | C | ... | .... | ... | 13 | 18 | 23 | 13 | 8 |

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TABLE 5—*Concluded*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dark green hornblende | A | 130 | 783 | 364 | 131 | 55 | 39 | 8 |
| | B | ... | 2 | ... | 8 | 16 | 10 | 26 |
| | C | ... | 48 | 359 | 251 | 42 | 42 | 22 |
| Gray-green hornblende | A | 780 | 2769 | 546 | 46 | 4 | 4 | ... |
| | B | ... | 2 | 10 | ... | 18 | 34 | 18 |
| | C | ... | 7 | 59 | 40 | 2 | ... | ... |
| Epidote | A | ... | 7 | 10 | 3 | 5 | 11 | 2 |
| | B | ... | ... | ... | ... | 2 | 4 | 8 |
| | C | ... | .. | 51 | 37 | 13 | 18 | ... |
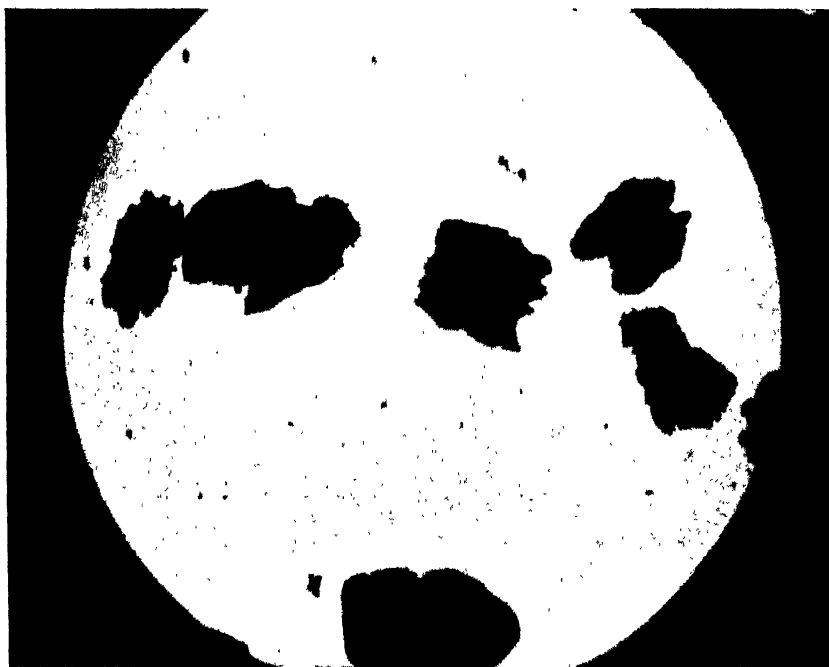


FIG. 2. PHOTOMICROGRAPH OF SEVERELY WEATHERED HORNBLENDE IN THE A HORIZON OF THE KALKASKA AND EMMET SANDS. 70 ×

the C horizon as a basis for measuring the grain-size change in the A horizon, the following phenomena were noted:

1. The A horizon of Rubicon sand appeared to be more severely weathered than other soils in group I.

2. The Kalkaska A horizon was the most severely weathered of the group II soils.
3. The grains in the A horizon of Kalkaska sand had decreased to a greater extent than those in the A horizon of Rubicon sand.

### Epidote

Epidote was not present in sufficient quantities in any of the soils except Wallace sand to justify definite statements on weathering. The microscopic count
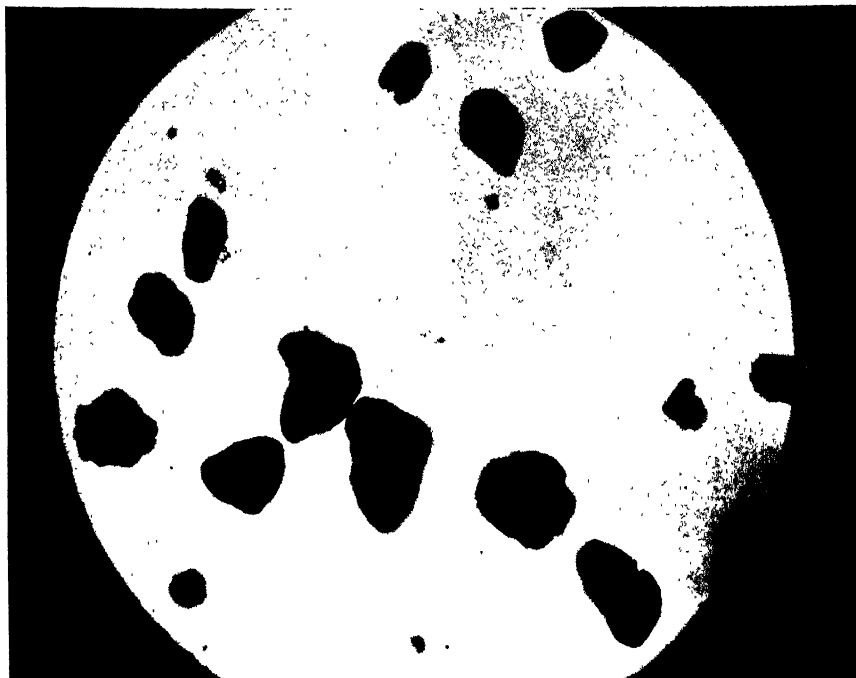


FIG. 3. PHOTOMICROGRAPH OF SLIGHTLY WEATHERED HORNBLENDE IN THE A HORIZON OF THE RUBICON, ROSELAWN, GRAYLING, AND EASTPORT SANDS. 70 ×

for any one grain size was usually less than 25 grains (tables 4 and 5). The A and C horizons of Wallace sand had a relatively high content of epidote. In the C horizon of Wallace sand the epidote grain count was at least three times as great as the grain count in any of the other sands.

### Opaque minerals

The opaque minerals were a dominant group of heavy minerals in all the soils studied. They ranked next to the hornblendes in total quantity. Magnetite constituted 90 per cent of the opaque minerals. Chandler (3) has pointed out that the relative resistance of the more important soil minerals to podzol weathering is as follows:

| Resistant | Moderately resistant | Easily weathered |
|---|---|---|
| zircon | epidote | hypersthene |
| magnetite | orthoclase | hornblende |
| quartz | diopside | plagioclase |
| garnet | | olivine |

TABLE 6

*Heavy-mineral count of opaque minerals in group I and II soils*

| SOIL TYPE AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Group I soils* | | | | | | | | | |
| Wallace sand | A | ... | 46 | 890 | 172 | 18 | 22 | .. | .. |
| | B | ... | 60 | 150 | 108 | 36 | 20 | 2 | 2 |
| | C | ... | ... | 589 | 624 | 240 | 29 | .. | .. |
| Kalkaska sand | A | ... | 74 | 398 | 178 | 19 | 7 | 4 | .. |
| | B | ... | 70 | 362 | 406 | 178 | 138 | 36 | 28 |
| | C | ... | ... | 232 | 475 | 103 | 50 | 7 | 24 |
| Emmet sand | A | ... | 3 | 567 | 399 | 147 | 19 | 8 | 11 |
| | B | ... | 26 | 112 | 200 | 40 | 52 | 30 | 24 |
| | C | ... | ... | 446 | 143 | 666 | 110 | 39 | 28 |
| *Group II soils* | | | | | | | | | |
| Rubicon sand | A | ... | 430 | 368 | 60 | 7 | 20 | 4 | .. |
| | B | ... | 82 | 10 | 32 | 18 | 22 | 26 | .. |
| | C | ... | ... | 8 | 53 | 27 | 47 | 24 | .. |
| Roselawn sand | A | ... | 7 | 116 | 275 | 40 | 28 | 7 | 5 |
| | B | ... | 60 | 54 | 118 | 58 | 78 | 12 | 2 |
| | C | ... | 25 | 75 | 50 | 8 | 11 | 8 | 6 |
| Grayling sand | A | ... | ... | 83 | 102 | 35 | 15 | .. | .. |
| | B | ... | 4 | 24 | 60 | 26 | 60 | 10 | 8 |
| | C | ... | ... | ... | 86 | 26 | 95 | 25 | 7 |
| Eastport sand | A | ... | 39 | 13 | 25 | 39 | 1 | 10 | 7 |
| | B | ... | ... | ... | 2 | 16 | 20 | 16 | 24 |
| | C | ... | 22 | 271 | 341 | 13 | 26 | 26 | 15 |

Cady (2) similarly found that magnetite and garnet seem to be little affected by podzolization.

In these studies (table 6), magnetite appeared to weather more rapidly in group I than in group II soils. A close examination of the data shows that in group I soils the mineral grains in the A horizon have decreased in size and total amount

TABLE 7

*Heavy-mineral count of brown, pink, and colorless garnet in group I soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS Maximum cross-sectional area | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Wallace sand* | | | | | | | | | |
| Brown Garnet | A | ... | 2 | 154 | 82 | 22 | 26 | 14 | .. |
| | B | ... | 22 | 12 | 22 | 6 | 8 | 6 | .. |
| | C | ... | 6 | 109 | 92 | 32 | 32 | 19 | .. |
| Pink garnet | A | ... | .. | 74 | 86 | 16 | 4 | 4 | .. |
| | B | ... | 12 | 12 | 8 | 6 | 4 | .. | .. |
| | C | ... | .. | 16 | 77 | 38 | 19 | 12 | ... |
| Colorless garnet | A | ... | .. | 168 | 104 | 18 | 18 | 6 | 10 |
| | B | ... | 20 | 16 | 18 | 2 | 2 | 6 | 10 |
| | C | ... | .. | 70 | 22 | 6 | 10 | 19 | 22 |
| *Kalkaska sand* | | | | | | | | | |
| Brown garnet | A | ... | 39 | 61 | 74 | 80 | 30 | 13 | .. |
| | B | ... | 2 | 12 | 26 | 14 | 20 | 24 | 2 |
| | C | ... | .. | 24 | 62 | 38 | 70 | 19 | .. |
| Pink garnet | A | ... | .. | 39 | 26 | 22 | 19 | 19 | .. |
| | B | ... | .. | 12 | 36 | 56 | 22 | 16 | .. |
| | C | ... | .. | ... | 48 | 14 | 14 | 5 | 5 |
| Colorless garnet | A | ... | 37 | 24 | 4 | 6 | ... | .. | .. |
| | B | ... | .. | 4 | 2 | 2 | 2 | 2 | 2 |
| | C | ... | 7 | 67 | 65 | 14 | 24 | 2 | 2 |
| *Emmet sand* | | | | | | | | | |
| Brown garnet | A | ... | .. | 38 | 59 | 13 | 34 | 15 | .. |
| | B | ... | .. | 8 | 12 | 12 | 4 | .. | .. |
| | C | ... | .. | ... | ... | 6 | 19 | 14 | 3 |
| Pink garnet | A | ... | 4 | 55 | 84 | 15 | 11 | 17 | .. |
| | B | ... | .. | 2 | 6 | 8 | 10 | 12 | .. |
| | C | ... | .. | ... | 3 | 3 | 6 | 10 | .. |
| Colorless garnet | A | ... | 6 | 23 | 23 | 2 | 4 | 4 | .. |
| | B | ... | .. | 2 | 10 | 4 | .. | 2 | .. |
| | C | ... | .. | ... | 10 | 6 | 14 | 17 | .. |

when compared to the C horizon. In group II soils (except Eastport) the mineral grains in the A horizon have accumulated.

The B horizons of group I soils had greater amounts of magnetite than did group II soils.

TABLE 8

*Heavy-mineral count of brown, pink, and colorless garnet in group II soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Rubicon sand* | | | | | | | | | |
| Brown garnet | A | ... | 51 | 26 | 27 | 6 | 16 | 8 | .. |
| | B | ... | 10 | 2 | 2 | 2 | 6 | 2 | 6 |
| | C | ... | .. | 3 | 14 | 2 | 26 | 21 | .. |
| Pink garnet | A | ... | 80 | 45 | 30 | 8 | 11 | 2 | .. |
| | B | ... | .. | 2 | 2 | 4 | .. | .. | .. |
| | C | ... | .. | 3 | 11 | 6 | 26 | 11 | .. |
| Colorless garnet | A | ... | .. | 15 | 5 | 1 | 1 | .. | .. |
| | B | ... | .. | 2 | 2 | 2 | .. | .. | 4 |
| | C | ... | .. | 3 | 3 | .. | 5 | .. | .. |
| *Roselawn sand* | | | | | | | | | |
| Brown garnet | A | ... | .. | 10 | 30 | 6 | 29 | 11 | .. |
| | B | ... | .. | .. | .. | 22 | 4 | 2 | 4 |
| | C | ... | .. | 5 | 14 | 8 | 19 | 5 | 10 |
| Pink garnet | A | ... | .. | 1 | 10 | 4 | 10 | 4 | .. |
| | B | ... | .. | .. | 6 | 12 | 8 | 2 | 10 |
| | C | ... | .. | 1 | 10 | 6 | 6 | 5 | .. |
| Colorless garnet | A | ... | .. | 7 | 34 | 2 | 7 | 5 | .. |
| | B | ... | .. | .*. | .. | 4 | .. | .. | 2 |
| | C | ... | 1 | 5 | 8 | 3 | 6 | 1 | 6 |
| *Grayling sand* | | | | | | | | | |
| Brown garnet | A | ... | 15 | 45 | 20 | 6 | 2 | 1 | .. |
| | B | ... | .. | .. | .. | 2 | 4 | 2 | 2 |
| | C | ... | .. | 1 | 3 | 7 | 17 | 9 | .. |
| Pink garnet | A | ... | 7 | 26 | 10 | 8 | 8 | 8 | .. |
| | B | ... | .. | .. | .. | 4 | 2 | 2 | 2 |
| | C | ... | .. | .. | 7 | 5 | 21 | 13 | .. |
| Colorless garnet | A | ... | 2 | 8 | 8 | 5 | .. | .. | .. |
| | B | ... | .. | .. | 2 | 2 | 2 | .. | 2 |
| | C | ... | .. | .. | .. | .. | 2 | .. | .. |

TABLE 8—*Concluded*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Eastport sand* | | | | | | | | | |
| Brown garnet | A | ... | 65 | 18 | 22 | 3 | 7 | 3 | .. |
| | B | ... | .. | .. | .. | 2 | 2 | .. | .. |
| | C | ... | .. | 7 | 42 | 11 | 59 | 18 | .. |
| Pink garnet | A | ... | 13 | 1 | .. | .. | .. | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | 4 | 24 | 20 | 9 | 7 | .. |
| Colorless garnet | A | ... | 4 | 3 | 1 | .. | .. | .. | ... |
| | B | ... | .. | .. | .. | 2 | .. | .. | .. |
| | C | ... | 2 | 31 | 53 | 7 | 2 | .. | .. |

A comparison of the data for garnet and the opaque minerals (tables 6 to 8), the two most resistant minerals studied, indicates that garnet was more resistant than the opaque minerals.

The presence of the more intense brown B horizon in the group I soils has always been difficult to explain. Data from table 1 and 2 suggest that this intense brown was due to a greater amount of iron oxide and organic matter. Mineralogical examinations (tables 4 to 8) indicated a greater weathering of the opaque and ferromagnesian minerals in group I soils. Birnbaum, Cohen, and Sidhu (1) have shown that the color change, ranging from yellow to dark brown, of synthetic iron oxide was caused mostly by particle growth. It is believed that the intense brown color due to the inorganic colloids may be explained by the greater original content of the opaque and ferromagnesian minerals and of the greater decomposition of these minerals in group I soils.

*Garnet*

Many workers have studied the use of resistant heavy minerals as index of soil development. In general, when soils weather, the resistant minerals show a relative concentration, whereas the less resistant decrease in relative abundance or disappear completely. In this investigation the resistant minerals, magnetite and garnet, decreased in size rather than accumulated. Zircon, tourmaline, anatase, rutile, magnetite, and garnet are the most common resistant minerals. Only garnet and magnetite were present in sufficient quantities in these podzols for comparative purposes.

The relative concentration of a resistant mineral can be determined accurately by comparing the size distribution of the entire sample. This is far too time-consuming. Moreover, a comparison of a very narrow grain size may lead to erroneous conclusions, since the choice of a particular grain size is purely arbi-

trary. This is brought out clearly by the data in tables 7 and 8 for the heavy-mineral count of brown garnet in Kalkaska and Rubicon sands. These mineral counts are of varying magnitude in all the grain sizes, and the choice of any one grain size would not give a complete picture of apparent garnet accumulation. In this investigation the grain-size limits were very wide, 0.25–0.02 mm. It was believed that a comparison of grain sizes within this wide range came nearer

### TABLE 9

*Heavy-mineral count of the minor minerals—tremolite, zircon, muscovite, and tourmaline—in group I soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Wallace sand* | | | | | | | | | |
| Tremolite | A | ... | ... | 34 | 2 | .. | .. | .. | .. |
| | B | ... | ... | ... | 2 | 2 | 2 | 2 | .. |
| | C | ... | ... | 6 | .. | .. | .. | 3 | .. |
| Zircon | A | ... | ... | 20 | 10 | .. | 2 | 2 | .. |
| | B | ... | 290 | 150 | 34 | 12 | 8 | 4 | 10 |
| | C | ... | 3 | 22 | 10 | .. | 3 | 3 | .. |
| Muscovite | A | ... | ... | 30 | 10 | .. | .. | .. | .. |
| | B | ... | ... | ... | .. | .. | .. | .. | .. |
| | C | ... | 3 | 32 | .. | .. | .. | .. | .. |
| Tourmaline | A | ... | ... | 6 | .. | .. | .. | .. | .. |
| | B | ... | 50 | 10 | .. | .. | .. | .. | .. |
| | C | ... | 3 | ... | .. | .. | .. | .. | .. |
| *Kalkaska sand* | | | | | | | | | |
| Tremolite | A | ... | 9 | ... | 2 | 6 | .. | 2 | 2 |
| | B | ... | 8 | 30 | 12 | 8 | 4 | .. | .. |
| | C | ... | ... | ... | 9 | .. | .. | .. | 2 |
| Zircon | A | ... | 9 | 6 | 6 | 15 | 6 | 4 | .. |
| | B | ... | 12 | 46 | 84 | 44 | 36 | 22 | 10 |
| | C | ... | ... | 13 | 2 | 5 | 5 | 2 | .. |
| Muscovite | A | ... | 33 | 24 | .. | .. | .. | .. | .. |
| | B | ... | ... | ... | .. | .. | .. | .. | .. |
| | C | ... | ... | 7 | 7 | .. | .. | .. | .. |
| Tourmaline | A | ... | 19 | 2 | 2 | .. | .. | .. | .. |
| | B | ... | 6 | 8 | .. | 2 | .. | .. | .. |
| | C | ... | 2 | 5 | 2 | .. | .. | .. | .. |

TABLE 9—*Concluded*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Emmet sand* | | | | | | | | | |
| Tremolite | A | ... | ... | 11 | 6 | .. | 6 | .. | .. |
| | B | ... | ... | 2 | 6 | 2 | 6 | .. | .. |
| | C | ... | ... | ... | .. | .. | .. | .. | .. |
| Zircon | A | ... | ... | 6 | .. | .. | .. | .. | .. |
| | B | ... | 4 | 20 | 14 | 14 | .. | 10 | .. |
| | C | ... | ... | ... | .. | 3 | 3 | .. | .. |
| Muscovite | A | ... | 4 | 13 | 6 | 4 | 6 | .. | .. |
| | B | ... | ... | .... | .. | .. | .. | .. | .. |
| | C | ... | ... | ... | 6 | .. | 6 | 8 | .. |
| Tourmaline | A | ... | 6 | 8 | .. | .. | .. | .. | .. |
| | B | ... | ... | 2 | .. | .. | .. | .. | .. |
| | C | ... | ... | ... | .. | .. | .. | .. | .. |

to deciding the actual quantity of resistant minerals in podzols than would a comparison of a very narrow grain-size range.

The mineral count and grain-size distribution of brown, pink, and colorless garnet is shown in tables 7 and 8. The garnet grains were more numerous in all horizons of group I soils than in group II. There was a greater decrease in size of the garnet grains from the C to the B horizon, than from the C to the A in all the soils. This might indicate a greater severity of weathering in the B horizon than in the A.

### Minor minerals

The minor minerals consisted of tremolite, zircon, muscovite, and tourmaline (tables 9 and 10). The mineral count of these from 20 gm. of organic-free soil was insufficient to provide any statistically significant comparisons between group I and group II soils. The results did show that zircon was present in high amounts in the Wallace soil.

### NEUBAUER TESTS

Neubauer tests are included here to help explain a type of weathering in podzols. It is believed that the heavy minerals, since they constitute a great variety and quantity of mineral species in these soils, could be utilized to measure relative growth of plants. Recent investigations by Graham (6, 7) suggested that organic matter closely surrounding the individual particles in the B horizons might decompose the fine sand particles for the nourishment of plants. Also,

it was thought that absence of organic matter, as in the C horizons, would result in little nutrient delivery to plants.

The Neubauer tests as used in these studies provided an indication of the relative nutrient delivery of the soil. The procedure and equipment for conducting the tests was that recommended by Thornton (13). All cultures were run in triplicate.

TABLE 10

*Heavy-mineral count of the minor minerals—tremolite, zircon, muscovite, and tourmaline—in group II soils*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES IN VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Rubicon sand* | | | | | | | | | |
| Tremolite | A | ... | 2 | 3 | 4 | .. | .. | .. | .. |
| | B | ... | .. | .. | .. | 2 | .. | .. | .. |
| | C | ... | .. | 2 | 6 | 2 | 8 | 2 | .. |
| Zircon | A | ... | 1 | 2 | 3 | 2 | 1 | .. | .. |
| | B | ... | 30 | .. | 6 | 10 | 6 | 6 | 4 |
| | C | ... | .. | .. | .. | 2 | .. | .. | .. |
| Muscovite | A | ... | .. | 5 | 9 | .. | | 1 | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | 2 | 2 | 2 | 2 | .. | .. |
| Tourmaline | A | ... | 10 | 2 | .. | .. | .. | .. | .. |
| | B | ... | . | .. | .. | .. | 2 | .. | .. |
| | C | ... | .. | .. | .. | .. | .. | .. | .. |
| *Roselawn sand* | | | | | | | | | |
| Tremolite | A | ... | .. | 1 | 3 | .. | .. | .. | .. |
| | B | ... | .. | .. | 8 | 2 | .. | 2 | .. |
| | C | ... | .. | 3 | .. | .. | .. | .. | .. |
| Zircon | A | ... | .. | 12 | 10 | 2 | 3 | 6 | .. |
| | B | ... | 2 | 6 | 8 | 4 | 2 | .. | .. |
| | C | ... | .. | 3 | 3 | 1 | .. | .. | .. |
| Muscovite | A | ... | .. | 9 | 6 | 2 | 3 | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | 10 | 1 | .. | 3 | .. | .. |
| Tourmaline | A | ... | .. | 3 | .. | .. | .. | .. | .. |
| | B | ... | .. | .. | 2 | .. | .. | .. | .. |
| | C | ... | .. | .. | .. | .. | .. | .. | .. |

TABLE 10—*Concluded*

| MINERAL AND HORIZON | | NUMBER OF PARTICLES ON VARIOUS HORIZONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum cross-sectional area | | | | | | | |
| | | 0.25 | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 6.0 | 10.0 |
| *Grayling sand* | | | | | | | | | |
| Tremolite | A | ... | .. | .. | .. | .. | .. | .. | .. |
| | B | ... | .. | .. | 4 | .. | 2 | 2 | .. |
| | C | ... | .. | .. | .. | .. | .. | 3 | .. |
| Zircon | A | ... | .. | 2 | 1 | 1 | .. | .. | .. |
| | B | ... | .. | 2 | .. | .. | 2 | .. | .. |
| | C | ... | .. | .. | .. | .. | 3 | 1 | .. |
| Muscovite | A | ... | .. | 1 | 1 | .. | .. | .. | .. |
| | B | ... | .. | 2 | .. | .. | .. | .. | .. |
| | C | ... | .. | .. | .. | .. | 3 | .. | .. |
| Tourmaline | A | ... | .. | .. | .. | .. | .. | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | .. | .. | .. | .. | .. | .. |
| *Eastport sand* | | | | | | | | | |
| Tremolite | A | ... | 1 | 3 | 4 | 1 | .. | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | 4 |
| | C | ... | .. | 9 | 4 | .. | .. | .. | .. |
| Zircon | A | ... | 7 | 8 | 8 | 5 | .. | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | 6 | .. |
| | C | ... | .. | 4 | 2 | .. | .. | .. | .. |
| Muscovite | A | ... | 52 | 20 | 20 | .. | 13 | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | 2 | 2 | .. | .. | .. | .. |
| Tourmaline | A | ... | 20 | 1 | .. | .. | .. | .. | .. |
| | B | ... | .. | .. | .. | .. | .. | .. | .. |
| | C | ... | .. | 9 | .. | .. | .. | .. | .. |

Rosen rye seed from South Manitou, Michigan, was dusted with Ceresan. The temperature of the air in the Minnesota Seed Germinator was maintained at 20 ±1° C. Distilled water was added as required. After 17 days the rye seedlings were removed, washed, air-dried for 2 hours, and weighed.

The results for the B and C horizons of all the soils are presented in figure 4. These results showed that the growth on the C horizon of all soils was approximately the same as that on the quartz-sand check. The tests suggest that there was no nutrient delivery from the soil minerals to the plant.

The growth on the B horizons showed a decided increase over that on the quartz-sand check. The greatest growth response was found on the Kalkaska and Emmet soils, which originally supported a hardwood cover. This indicated a greater nutrient delivery from the B horizons than from the C. Since the sand particles of the B horizons of the Kalkaska and Emmet soils are higher in coatings of organic matter than most of the other soils studied, it was believed that the presence of the organic matter assisted in the decomposition of the heavy minerals, particularly the dark green hornblende in the fine sand fraction. The magnitude of this decomposition varied with the amount and type of organic matter. The presence of relatively large quantities of heavy minerals without organic matter failed to effect sufficient plant nutrient delivery.
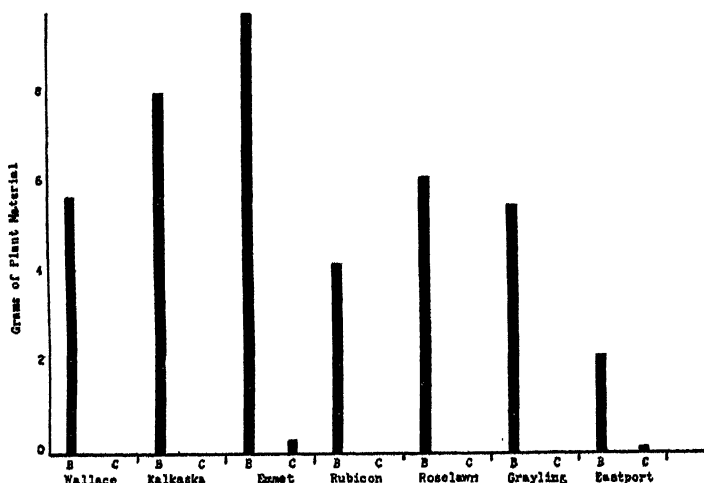


FIG. 4. INCREASE OF PLANT MATERIAL OVER CHECK IN NEUBAUER TESTS

## SUMMARY AND CONCLUSIONS

A study was made of the heavy minerals in the fine sand fraction of some Michigan podzols. Detailed data obtained from petrographic observations, mechanical and chemical analyses, and Neubauer tests were compared to indicate a type of soil weathering. A summation of the results and of the conclusions follows:

The brown B horizon of some Michigan podzols is the result of a vigorous decomposition of a relatively high original content of opaque and ferromagnesian minerals.

Organic matter is an effective weathering agent of some heavy minerals in the B horizons.

The least resistant mineral to podzol weathering was found to be dark green hornblende, followed by gray-green hornblende, the opaque minerals, and the garnets.

The relative resistance to weathering varied within the profile. In general, the B horizons suffered a greater decomposition of the heavy minerals than did the A or C horizons.

Kalkaska and Emmet sands (soils that support a hardwood cover) contain a greater quantity of calcium and magnesium heavy minerals in all horizons of the profile than do Wallace, Rubicon, Roselawn, and Grayling sands (soils that support a pine cover).

Wallace sand showed marked differences in the microscopic count of heavy minerals from the other soils investigated.

A similar heavy mineral assemblage was found in the group I (Wallace, Roselawn, Grayling, and Eastport) soils, although the quantity of heavy minerals was lower in the group II soils.

Quantitative data on the heavy minerals were difficult to obtain. More accurate results were obtained by subjecting the entire fine sand fraction, rather than a small part, to heavy-mineral analyses.

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# AZOTOBACTER INOCULATION OF CROPS: II. EFFECT ON CROPS UNDER GREENHOUSE CONDITIONS

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The review of earlier investigations on the use of Azotobacter as a seed and soil inoculant, presented in the previous report[3], emphasized the wide differences in the results and opinions of research workers from various nations. The many marked increases in crop yields reported by Soviet workers stand out in vivid contrast to the negative results reported by most workers elsewhere. These recent positive results emphasize the need for a reexamination by workers outside the USSR of possible benefits of soil inoculation with nonsymbiotic nitrogen-fixing bacteria.

The studies reported in the present paper were conducted for the purpose of determining, under controlled greenhouse conditions, whether crop inoculation with Azotobacter is of value under any of a wide variety of conditions with respect to soil, crop, available carbon, available nitrogen, strain of Azotobacter, and method of inoculation. Should the Soviet findings be corroborated, it was planned to investigate more specifically the manner in which Azotobacter exerts its effects.

## EXPERIMENTAL METHODS

These experiments were conducted in the greenhouse in 2-gallon glazed pots, which held either 18 pounds of Evesboro loamy sand or 16 pounds of Chester loam, both unsterilized. These soils, which had initial pH values of 4.8 and 5.5, respectively, were limed with calcium hydroxide to near neutrality. The soils were then brought up to optimum moisture content and allowed to stand for 3 or 4 weeks. At the end of this time a ton per acre of calcium carbonate was added to make certain that no trace of acidity remained. Shortly thereafter, 2,000 pounds of a 0-15-6 fertilizer, supplied with adequate magnesium, and a solution containing the necessary amounts of boron, copper, zinc, manganese, and molybdenum, were added.

Since the three experiments varied with regard to additions of available nitro-

gen and organic matter, crops grown, and methods and source of inoculation, these are described separately in connection with each experiment. Other details of set up, as well as of harvesting and analysis, are also given later.

## EXPERIMENTAL RESULTS

### Effect of Azotogen on growth of Swiss chard and Sudan grass

In the first experiment both Evesboro loamy sand and Chester loam were used. In addition to the lime and fertilizer treatments already mentioned, the Evesboro soil received an application of 4 tons per acre of dried immature millet (1.2 per cent nitrogen) having a carbon-nitrogen ratio of 35. This ratio is such that the millet would furnish little or no nitrogen to the first crop but would serve as a source of energy for the added Azotobacter. No other source of nitrogen was

TABLE 1

*Effect of inoculation with Azotogen on yields and nitrogen contents\* of Swiss chard and Sudan grass*

Averages of 5 replications

| TREATMENT | EVESBORO SOIL | | | CHESTER SOIL | | |
|---|---|---|---|---|---|---|
| | Dry weight of first crop | Dry weight of 3 crops | Total N in 3 crops | Dry weight of first crop | Dry weight of 3 crops | Total N in 3 crops |
| | *gm.* | *gm.* | *mgm.* | *gm.* | *gm.* | *mgm.* |
| Swiss chard | | | | | | |
| Uninoculated............... | 9.5 | 18.6 | 403.3 | 13.8 | 24.6 | 719.3 |
| Inoculated.................. | 9.0 | 17.6 | 386.8 | 13.9 | 25.3 | 720.4 |
| Sudan grass | | | | | | |
| Uninoculated............... | 35.6 | 48.2 | 329.2 | 42.2 | 61.8 | 594.9 |
| Inoculated.................. | 34.6 | 46.4 | 320.9 | 42.3 | 60.7 | 560.6 |

\* Nitrogen analyses made by Mrs. Luann D. Sterling.

added, even though it was known that the amount that would be made available in the soils would not be adequate for more than about half maximum growth. Such a partial nitrogen deficiency was planned to allow the added Azotobacter to exercise its maximum nitrogen-fixing powers.

The experiment was set up as a 2 by 2 by 2 factorial arranged in five blocks corresponding to the five replications. Inoculation was made according to the Soviet recommendations by wetting the seeds with a water suspension of Azotogen obtained from the USSR. In addition, a drop of the suspension was added directly to each seed after it was planted and just before it was covered. The Swiss chard and Sudan grass were planted on May 29, 1945, immediately after the mineral elements (other than calcium hydroxide) and the millet were mixed with the soils.

Three cuttings of both crops were made from the original plants on the 51st, 94th, and 124th days after planting. No additional fertilization or inoculation

was given subsequent to the initial treatments. The average dry weights of the first crop and the total weights of the three crops are given in table 1. The total quantity of nitrogen in the harvested parts of the crops is also given in table 1.

These data show no effect of inoculation with Azotogen on either the yields or nitrogen contents of the plants. Even though conditions were made ideal for the action of nitrogen-fixing bacteria, there is no evidence that such fixation occurred. Samples of the soil taken from the pots at the end of the first harvest showed Azotobacter present in less than half of the inoculated pots. No examinations of the root surfaces, apart from the soil, for these organisms was made.

*Effect of Azotogen and pure cultures of Azotobacter on growth of rye,*
*barley, kale, and rape*

The Evesboro soil was used for the second experiment. In addition to the usual fertilizer and lime treatments, all pots received an addition of 4 tons per acre of the dried green millet, containing 1.2 per cent nitrogen. This was the only form of nitrogen supplied, and it was unavailable to the first crop, as has been pointed out. This experiment, like the first, was therefore conducted under conditions of limited nitrogen supply.

At the time of planting, the seeds of the four crops were inoculated according to the following scheme:

(a) Uninoculated. Control pots both with and without the addition of 0.75 gm. of sucrose were included. The sugar application corresponds approximately to the amount of sucrose added in the inoculum of treatments c to f described below.

(b) Azotogen as distributed. Seventy-five milliliters of a suspension of Azotogen in water was pipetted on the seed of each pot after it was planted and before it was covered with soil.

(c) Azotogen was added as an inoculant to a sterile nitrogen-free Azotobacter medium, and 75 ml. of the heavy 5-day culture was added to the seed of each pot at planting time.

(d) Seventy-five milliliters of a heavy 2-day pure culture of A. chroococcum, isolated from Azotogen, was added to the seed in each pot.

(e) Seventy-five milliliters of a heavy 6-day pure culture of A. chroococcum No. 12, taken from stock, was added per pot.

(f) Inoculum was the same as in c except that it was mixed with all the soil in the pot.

In all cases except f the seeds were dropped into small holes and the bacteria were pipetted on the seeds, which were covered immediately with soil.

The pots were arranged as a split plot design, with the split on the kind of crop, thus providing for a more accurate test of inoculation. All treatments were replicated three times. The inoculation treatments were randomized within each subblock. The four crops were planted on November 15, 1945, 10 days after the addition of the fertilizer and green manure crop.

Although the experiment was designed primarily to test the effect of inoculation on the first crop, additional cuttings were made in some cases from the original plants. No fertilizer or inoculation treatments were made other than the

original ones. The time in days that elapsed from the date of seeding to the date of the various harvests was as follows:

|       | 1st | 2nd | 3rd | 4th |
|-------|-----|-----|-----|-----|
| Rye   | 62  | ... |     |     |
| Barley| 81  | 159 |     |     |
| Kale  | 90  | 134 | 169 | 215 |
| Rape  | 90  | 134 | 169 | 215 |

The average dry weights of the first crop and of the total crops, where more than one cutting was made, are given in table 2. The corresponding data for nitrogen contents of the crops are reported in table 3.

TABLE 2

*Effect of inoculation on yields of rye, barley, kale and rape*

Averages of 3 replications

| INOCULATION TREATMENT | RYE | BARLEY | | KALE | | RAPE | |
|---|---|---|---|---|---|---|---|
| | Dry weight* of crop | Dry weight* of first crop | Dry weight of 2 crops | Dry weight* of first crop | Dry weight of 4 crops | Dry weight* of first crop | Dry weight of 4 crops |
| | gm. | gm. | gm. | gm. | gm. | gm. | gm. |
| (a) Uninoculated, no sugar.......... | 6.9 | 15.1 | 29.3 | 23.4 | 45.9 | 20.1 | 40.0 |
| (a) Uninoculated, with sugar..... | 6.6 | 15.0 | 28.9 | 22.9 | 44.3 | 19.8 | 39.3 |
| (b) Azotogen........ | 6.8 | 15.1 | 27.1 | 24.1 | 46.2 | 21.3 | 40.9 |
| (c) Azotogen, cultured......... | 7.1 | 15.7 | 29.1 | 24.7 | 46.1 | 21.1 | 40.0 |
| (d) Azotobacter from Azotogen | 6.9 | 15.0 | 29.0 | 24.4 | 47.1 | 20.4 | 38.8 |
| (e) Azotobacter No. 12............ | 7.0 | 14.6 | 28.5 | 24.0 | 45.7 | 21.3 | 40.3 |
| (f) Azotogen, cultured, mixed with soil....... | 7.1 | 16.2 | 30.7 | 24.6 | 44.1 | 21.8 | 41.0 |

\* Least significant difference at 5 per cent level = 1.49.

In general, the effects produced by inoculation were small or negligible for all four crops. Inoculation with Azotobacter increased the dry weights of the first cuttings of the four crops an average of 3.8 per cent. The analysis of variance showed that this increase was just under significance at the 5 per cent level for the data as a whole. Two of the five inoculations were, however, barely significant. These were the ones with cultured Azotogen (c and f), either added to the seed or mixed with all the soil in each pot. The crop × inoculation interaction was not significant.

Inoculation with Azotobacter increased the average nitrogen content of the first crops 3.7 per cent. This increase, although no larger than that for dry weights, was significant at the 1 per cent level. All five methods of inoculation increased the nitrogen contents slightly, but only the use of cultured Azotogen,

or of *A. chroococcum* No. 12, produced increases that were significant. The effect of inoculation was again independent of crop.

Comparison of yields and nitrogen contents of the controls, with and without added sugar, shows that the sugar had a slightly depressing effect, but this small effect was not significant.

The data also show that there was no beneficial effect of inoculation on either the dry weights or nitrogen contents of the later cuttings of barley, rape, and kale. In fact, usually the lower weights and nitrogen contents of the later cuttings from the treated pots, as compared with the controls, offset any slight gains found for the first cuttings. Undoubtedly the first crops removed virtually all

TABLE 3

*Effect of inoculation on nitrogen contents\* of rye, barley, kale, and rape*

Averages of 3 replications

| INOCULATION TREATMENT | RYE | BARLEY | | KALE | | RAPE | |
|---|---|---|---|---|---|---|---|
| | Total N† in crop | Total N† in first crop | Total N in 2 crops | Total N† in first crop | Total N in 4 crops | Total N† in first crop | Total N in 4 crops |
| | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* | *mgm.* |
| (a) Uninoculated, no sugar......... | 274 | 265 | 393 | 288 | 572 | 270 | 541 |
| (a) Uninoculated, with sugar..... | 256 | 275 | 402 | 282 | 555 | 271 | 542 |
| (b) Azotogen........ | 258 | 259 | 394 | 314 | 591 | 281 | 540 |
| (c) Azotogen, cultured.......... | 276 | 272 | 403 | 302 | 577 | 281 | 544 |
| (d) Azotobacter from Azotogen | 266 | 276 | 417 | 303 | 586 | 270 | 517 |
| (e) Azotobacter No. 12............ | 280 | 265 | 394 | 317 | 602 | 285 | 522 |
| (f) Azotogen, cultured, mixed with soil...... | 288 | 285 | 429 | 316 | 584 | 295 | 546 |

\* Nitrogen analyses made by Mrs. Luann D. Sterling.

† Least significant difference at 5 per cent level = 20.

the available soil nitrogen, and this should have made conditions ideal for a high rate of nitrogen fixation by Azotobacter living in the rhizosphere on the root excretions. The fact that the bacteria produced no beneficial effects on the later harvests under these conditions serves as strong evidence against the nitrogen fixation theory that has been held by some Soviet investigators.

*Effect of Azotogen and pure cultures of Azotobacter chroococcum on barley grown at varying levels of available soil carbon and nitrogen*

The first two experiments seemed to indicate the need for Azotobacter inoculation studies at varying levels of available soil nitrogen and energy sources. Such studies, reported below, should not only give a further test of the hypothesis

that nitrogen is fixed in the rhizosphere but also furnish evidence as to whether the bacteria secrete substances that stimulate plant growth.

Chester loam was used in this experiment. After the soil was limed and allowed to stand in the greenhouse for a month, the nitrate content was found to be too high to permit conducting the experiment at a low, as well as at a high, nitrogen level. A portion of the soil was therefore given a preliminary cropping to lower the available nitrogen level. Additions of 150 pounds of $P_2O_5$ and 100 pounds of $K_2O$ per acre were made to the soil, which was then seeded to Sudan grass. This was harvested when the heads began to form. After removal of the roots, in addition to the tops, the soil was thoroughly mixed in one lot and repotted. It now had a pH value of 6.6 and contained 35 p.p.m. of nitrate nitrogen. To half of the pots containing the cropped soil was added 25 pounds per acre of nitrogen in the form of urea and to the other half 200 pounds of urea nitrogen. All of the cropped soils received an additional application of 200 pounds of $P_2O_5$ and 80 pounds of $K_2O$ per acre, as well as the usual 2,000 pounds of calcium carbonate and minor elements just prior to planting of the experimental crop, barley. In addition, another group of pots was filled with some of the original uncropped soil. This soil received the standard treatments of lime, minor elements, and 2,000 pounds of 0-15-6 fertilizer. An application of 5 tons (dry weight) per acre of dried green millet (1.2 per cent nitrogen) was made to half of the pots, containing both cropped and uncropped soil, in order to furnish an abundant supply of available energy for the Azotobacter.

Inoculation was made at the time of seeding, except as noted, according to the following methods:

(a) Uninoculated.
(b) Azotogen as obtained from the U. S. S. R.
(c) A. chroococcum No. 12. The barley seeds were allowed to soak for 24 hours at 12° C. in a heavy 4-day culture of the bacteria.
(d) A. chroococcum No. 12. Fifty milliliters of a 4-day culture was added to the seed at the time of planting.
(e) Same as d except that a second 50-ml. portion of bacteria was added to the seeds 52 days after planting.
(f) Same as d except that a pure culture of A. chroococcum, isolated from Azotogen, was used.

The experiment was conducted as a 2 by 3 by 6 factorial with three replications. The arrangement of the pots on the greenhouse bench was according to a split plot design. The first split was on the basis of the presence or absence of the green manure crop, and the second split was on the nitrogen level in the soil. The inoculation treatments were then randomized in each subsubplot. The pots were seeded to Manchurian spring barley on November 5, 1946 and harvested on March 10, 1947 when fully mature.

The total dry weights of the crop, as well as the separate weights of barley grain and straw, variously inoculated, are given in table 4. At all three nitrogen levels comparative results for the soil with and without the green manure addition are shown. Incidentally, this green manure, containing 1.2 per cent nitro-

gen, had little effect upon the crop yields. This confirms previous results from this laboratory[4] in showing that at a carbon-nitrogen ratio of approximately 35 for added fresh plant material, nitrogen is neither taken up by soil microorganisms, in quantities greater than released, nor made available to the first crop.

The data in table 4 show that in no case did any one of the methods of inoculation produce a significant increase in the barley yields. This held true whether

TABLE 4

*Effect of inoculation with* Azotobacter chroococcum *on yields of barley grown on Chester loam of varying available nitrogen content*

| INOCULATION TREATMENT | WITHOUT GREEN MANURE | | | WITH GREEN MANURE | | |
|---|---|---|---|---|---|---|
| | Grain | Straw | Total* | Grain | Straw | Total* |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| *Cropped soil—low available nitrogen* | | | | | | |
| (a) Uninoculated.............................. | 13.7 | 25.1 | 38.8 | 11.6 | 23.6 | 35.2 |
| (b) Azotogen................................. | 14.3 | 25.4 | 39.7 | 13.0 | 22.3 | 35.3 |
| (c) Azotobacter No. 12, seed soaked............. | 14.4 | 25.6 | 40.0 | 11.0 | 23.6 | 34.6 |
| (d) Azotobacter No. 12, 50 ml. of culture........ | 13.5 | 25.4 | 38.9 | 13.4 | 23.4 | 36.8 |
| (e) Azotobacter No. 12, two 50-ml. portions..... | 14.1 | 26.9 | 41.0 | 12.6 | 23.2 | 35.8 |
| (f) Azotobacter from Azotogen, 50 ml........... | 15.2 | 25.0 | 40.2 | 12.4 | 23.7 | 36.1 |
| *Cropped soil—high available nitrogen* | | | | | | |
| (a) Uninoculated.............................. | 20.3 | 44.4 | 64.7 | 25.3 | 46.2 | 71.5 |
| (b) Azotogen................................. | 20.1 | 45.7 | 65.8 | 26.7 | 45.5 | 72.2 |
| (c) Azotobacter No. 12, seed soaked............. | 19.8 | 45.2 | 65.0 | 27.4 | 47.1 | 74.5 |
| (d) Azotobacter No. 12, 50 ml. of culture......... | 18.3 | 46.3 | 64.6 | 24.7 | 46.9 | 71.6 |
| (e) Azotobacter No. 12, two 50-ml. portions....... | 20.5 | 45.9 | 66.4 | 25.2 | 46.9 | 72.1 |
| (f) Azotobacter from Aztogen, 50 ml............. | 21.4 | 45.9 | 67.3 | 25.3 | 46.2 | 71.5 |
| *Uncropped soil—high available nitrogen* | | | | | | |
| (a) Uninoculated.............................. | 26.9 | 45.7 | 72.6 | 26.0 | 47.2 | 73.2 |
| (b) Azotogen................................. | 27.0 | 47.8 | 74.8 | 21.3 | 41.2 | 62.5 |
| (c) Azotobacter No. 12, seed soaked............. | 28.7 | 46.4 | 75.1 | 26.5 | 46.5 | 73.0 |
| (d) Azotobacter No. 12, 50 ml. of culture........ | 27.9 | 45.8 | 73.7 | 25.5 | 43.4 | 68.9 |
| (e) Azotobacter No. 12, two 50-ml. portions..... | 27.7 | 46.9 | 74.6 | 25.4 | 49.7 | 75.1 |
| (f) Azotobacter from Azotogen, 50 ml........... | 28.7 | 48.2 | 76.9 | 25.5 | 44.7 | 70.2 |

* Least significant difference at the 5 per cent level = 4.6.

or not green millet was added. In view of the negative results, an analysis of the crop for total nitrogen was not made.

The results of this experiment, therefore, agree with the previous findings in showing that neither freshly prepared Azotogen nor mass additions of pure cultures of *A. chroococcum* had an appreciable effect on crop growth under the experimental conditions. This latest experiment is, however, more conclusive

[4] Pinck, L. A., Allison, F. E., and Gaddy, V. L. 1946 The nitrogen requirement in the utilization of carbonaceous residues in soil. *Jour. Amer. Soc. Agron.* 38: 410–420.

than either of the others, since the important variables are more adequately tested.

The experiments reported agree in showing no significant effect of inoculation of various nonlegume crops with Azotogen or with pure cultures of *A. chroococcum*. No combination of soil, crop, source or method of inoculation, soil nitrogen content, or soil organic matter supply resulted in an appreciable increase in either yields or nitrogen content of the crops.

These negative findings[5] are in disagreement with many of the data reported from similar experiments conducted in the USSR. The reason is not evident. It is well to bear in mind, though, that Soviet workers do not always obtain positive results, nor do they agree as to the exact reason for the increased yields that they have frequently obtained. It is to be hoped that those workers who have had no difficulty in obtaining large benefits from the use of Azotogen will soon determine the exact conditions that lead to maximum increases. In the absence of such information it would seem that further experimentation of the type reported here is not likely to prove profitable.

In the first paper of this series it was pointed out that the beneficial effect of inoculation with Azotobacter, reported by Soviet workers, is explained by them as due to (a) nitrogen fixation in the rhizosphere, (b) protection of the higher plant against pathogenic organisms, or (c) production of plant growth accelerators by the bacteria. Since only negative results were obtained by us, there was obviously no opportunity to test the relative merits of these three suggested explanations. The present experiments do, however, furnish strong evidence against the nitrogen-fixation theory, since the experimental conditions were such as to favor fixation. They do not, of course, furnish nearly so strong evidence against either of the other two explanations. Disease apparently was not an appreciable factor in the yields, and there was also no reason for suspecting that the plants needed an external source of vitamins or growth regulators. Under other conditions, it is possible that growth regulators might increase crop yields. This possibility seems more likely than that Azotobacter would either fix large quantities of nitrogen in the rhizosphere or appreciably depress the pathogenic soil organisms. Proof that growth regulators can increase the yields of crops grown in normal soils has not yet been presented.

SUMMARY

The results of greenhouse experiments, dealing with the effect of inoculation with *Azotobacter chroococcum* on the yields and nitrogen contents of several non-legume crops, are reported. The experiments were conducted in two soils at varying levels of available nitrogen and carbon. Several methods of inoculation,

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[5] It is of interest in this connection to mention that in a field experiment recently conducted at Bard, California, by E. G. Noble and Norris W. Gilbert of this Division, the yields of barley were not increased significantly as a result of inoculation with Azotogen.

using pure cultures of Azotobacter and Azotogen prepared in the USSR, were tried.

No significant effect of inoculation on growth or nitrogen content of barley, Sudan grass, kale, rape, rye, or Swiss chard was observed under the various growth conditions. The experiments present strong evidence against the theory, held by several Soviet scientists, that Azotobacter when living in the rhizosphere of plants benefits higher plants by fixing considerable quantities of nitrogen. If inoculation of soils with Azotobacter does result in increased yields it would seem more likely to be the result of the production of growth regulating or stimulating substances by the bacteria. There is no direct evidence to support this idea, however, and under the experimental conditions of the present studies no such effect was observed.

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